Examining Physical Activity Intensity and Continuation in Weight Loss Seeking and Non-Weight Loss Seeking Adult Samples

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Dedication

For my mom, the first person to show me that a little ambition looks good on a lady; you are my hero.

Abstract

This dissertation consists of three investigations covering topics on physical activity achievement and continuation and its relationship with body weight in two intervention samples. The data for the first two papers come from the Tracking Study weight loss intervention trial, while data for the third paper come from the Stand & Move at Work group-randomized worksite LPA intervention trial. Manuscript 1 examined the relationship between the occurrence of life events, MVPA achievement and weight loss maintenance success following a lifestyle weight loss intervention using a 4-way mediation and moderation decomposition analysis. Findings suggested that the effects of life events and MVPA on weight loss maintenance should be considered as separate effects when considering weight loss maintenance and designing interventions to prevent weight re-gain. Manuscript 2 utilized behavior-tracking logs during a weight loss intervention to identify individuals who may show signs of behavioral disengagement and increased weight. General Estimating Equation (GEE) modeling was used to examine the association between physical activity self-monitoring characteristics and reported MVPA participation and weight measured at 12-month and 24-month follow-up. Results showed various self-monitoring characteristics were associated with MVPA participation and weight at 12- and 24-month time points, suggesting that behavior-tracking characteristics should be used to monitor intervention engagement. Manuscript 3 explored differences in LPA participation by BMI category. Hierarchical models examined the association of BMI category with baseline work time LPA participation, total daily LPA participation, and work time LPA participation over time from baseline to 3 months. At baseline there were no statistical differences in work time LPA participation

across BMI categories. At three months, participants with BMI in normal and overweight categories participated in work time LPA longer than participants with BMI in the obese category. The findings of this dissertation inform future intervention design and measurement implications for behavioral science and epidemiology.

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CHAPTER 1

Introduction

The prevalence of overweight and obesity in adults has recently been estimated to have reached 68.5% in the U.S.[1] An investigation of weight control practices using data collected from the National Health and Nutrition Examination Survey (NHANES) found that more than half of individuals with obesity reported trying to lose weight in the past year and 40% of attempters achieved a weight loss of at least 5% of their baseline weight[2]. These findings suggest that U.S. adults are making deliberate attempts to lose weight; however, many individuals who have participated in some form of active weight loss are unable to keep this weight from returning. Due to the health risks of obesity as well as the attenuation of these risks by weight loss[3, 4], successful maintenance of weight loss has become an important goal for public health. Studies of the National Weight Control Registry (NWCR) have found that continued high levels of physical activity (PA) were associated with more successful weight maintenance after losing substantial amounts of weight[5]. Consistent PA has on its own been shown to improve cardiovascular health, glycemic control, musculoskeletal health, and psychological well-being [6-11]. As support for the continuation of regular PA in order to improve health outcomes both through weight control and beyond continues to grow, topics covering the relationship between PA maintenance and weight warrant a closer look. This dissertation informs intervention development and design by examining potential strategies to support PA continuation as well as exploring further the impact of PA on weight loss maintenance as individuals manage occurring life events.

In order to look more thoroughly at several aspects of weight loss maintenance, as well as variables that support PA recommendation adherence, secondary data analyses from a weight loss intervention trial and a worksite intervention trial designed to increase light intensity physical activity (LPA) and limit sedentary time were utilized. The Tracking Study enrolled 339 adults into a yearlong lifestyle weight loss intervention incorporating moderate to vigorous physical activity (MVPA) recommendations, with a yearlong follow-up [12]. Weight changes from baseline through 24-month follow-up were used to examine various relationships between weight and self-reported demographic characteristics, self-monitoring behavior measures, life experiences and MVPA participation. The Stand & Move at Work intervention trial enrolled 641 employees across 24 worksites for a yearlong LPA intervention with a planned yearlong follow-up [13]. LPA participation from baseline and 3-months collected through objective measures were used to examine success of LPA recommendations for promoting participation and continuation, as moderated by obesity status.

This research investigated more precisely the relationships described above by addressing the following aims:

Aim1. Identify changes in weight following a lifestyle weight loss program by examination of the impact of physical activity in the context of life events on those changes.

Hypothesis 1: The total effect of greater reporting of life events on weight within a lifestyle weight loss intervention will be influenced by individuals' physical activity levels during the maintenance phase.

Hypothesis 1a: a portion of the effect of reported life events on weight following a behavioral weight loss intervention will be moderated by physical activity level during the maintenance period, such that individuals who participate in higher levels of physical activity will weigh less at 24 months despite life events experienced.

Hypothesis 1b: a portion of the effect of reported life events on weight following a behavioral weight loss intervention will be mediated by physical activity during the maintenance period, so that the occurrence of significant life events will lead to increased weight through low participation in MVPA.

Aim 2. Examine the effect of physical activity tracking behavior during active weight loss intervention on moderate to vigorous physical activity achievement and maintenance, weight loss at 12 months (immediately following intervention), and weight loss maintained at 24-month follow-up.

Hypothesis 1: Later onset and greater frequency of gaps in of physical activity self-monitoring during intervention will be associated with lower reported physical activity levels measured at 12-month and 24-month follow-up.

Hypothesis 2: Later onset and greater frequency of gaps in physical activity self-monitoring during intervention will be associated with higher weight at 12 and 24-month follow-up.

Aim 3. Examine the association between baseline BMI and light intensity physical activity at baseline and 3-months during a light intensity physical activity worksite intervention.

Hypothesis 1: Baseline BMI will be inversely associated with physical activity measured at baseline, so that employees with higher BMI will have participated in light intensity physical activity less frequently than employees with lower BMI prior to intervention.

Hypothesis 2: Baseline BMI will no longer be inversely associated with light intensity physical activity participation at 3 months during a worksite intervention aimed at increasing light intensity physical activity participation to 30 minutes during the workday.

By examining the relationship between PA continuation and weight loss maintenance as well as factors that lead to successful PA continuation, including the demands of PA intensity recommendations and environmental and social influences across two disparate interventions, this dissertation improves understanding of behavioral maintenance and its correlates. Finally, this work identifies characteristics of intervention design and recommendations to enhance successful PA adoption and continuation.

CHAPTER 2

BACKGROUND AND RATIONALE

Obesity and weight loss

Age-adjusted prevalence estimates of overweight and obesity in American adults have reached 68.5% [1]. In general, without any intervention, adults tend to gain weight over time [14], with estimates ranging from 0.5 to 1 kg on average each year [15]. This has been observed at the population level, with the prevalence of overweight and obesity having increased across all education levels and ethnic backgrounds over time [16]. This poses a risk to both individual and population health due to the high rates of mortality and morbidity related to obesity[17]. Higher rates of cardiovascular disease, cancer, metabolic syndrome, and other chronic diseases have all been found to be associated with obesity [18]. Quality of life analyses also suggest that high BMI is associated with psychosocial impairment and reduced physical functioning[19]. The increased prevalence of obesity has consequently raised medical care costs. A recent study estimated the cost of medical care associated with obesity in the United States to be around $127 billion per year [20]. Beyond increased healthcare costs and morbidity, obesity has continuously been associated with higher risk of all cause mortality[21].

Fortunately, there is evidence that moderate weight loss by obese individuals is sufficient to attenuate the risk for many of these diseases and show beneficial health outcomes[22, 23]. A systematic review of obesity treatment outcomes suggested that a weight loss of approximately 5-10 kg was associated with improved health markers for both cardiovascular disease and diabetes[23]. Further, behavioral interventions have had reasonable success in helping individuals to achieve clinically relevant weight loss of 8-10 kg [24-26]. Research into weight loss practices has suggested that a high proportion of adults are making some effort to lose weight. One survey of U.S. adults estimated that 34% of men and 48% of women participated in some form of attempted weight loss in a one-year period[27]. Additionally, work using NHANES data showed that when asked about attempted weight loss in the past year, more than half of obese individuals reported trying to lose weight and 40% of attempters achieved a weight loss of at least 5% of their baseline weight[2]. Though self-reported, this information is congruent with findings from other pharmaceutical, behavioral, and lifestyle interventions suggesting that clinically relevant weight loss is indeed achievable through such interventions[24, 28, 29]. Therefore, interventions that aid in sustaining those weight losses and preventing regain after weight loss successes are of public health relevance.

Weight loss maintenance and physical activity

Weight loss maintenance and prevention of regain continue to be challenging; research has found that high proportions of people who do lose a substantial amount of weight are unable to prevent re-gain. Two studies using data from random digit dialing and NHANES samples estimated that of those individuals who lost ≥10% of their body weight, 51% and 33% experienced regain[27, 30]. In order to explore behaviors and characteristics associated with successful weight loss maintenance over time, researchers assembled the NWCR, a cohort of individuals who have lost at least 30 lbs. and maintained this weight loss for at least one year. Using this cohort, researchers identified frequent MVPA as a common behavior in those who have been successful at preventing weight regain[31-33]. Those in this cohort reporting the highest levels of MVPA weighed less at enrollment and gained less weight over time[32]. This cohort is comprised of a very unique group of individuals; on average, members have lost over 60 lbs. and have successfully maintained at least a 30 lb. weight loss for over 6 years[34]. Though this amount of weight loss and maintenance is uncommon across the U.S. population, the behaviors and strategies of NWCR members are of interest and have informed current weight loss maintenance research.

Weight loss maintenance interventions focusing on diet, PA and a combination of both have had moderate success in sustaining weight losses. In a recent meta-analysis on long-term weight maintenance using only randomized trials, Dombrowski and others found that weight loss maintenance interventions shown a mean difference of -2.34 kg (95% CI: -3.03 kg, -1.64 kg) between intervention and comparison groups[35]. However, the researchers noted substantial heterogeneity across study design and intervention. Further, only four studies of 45 reviewed had outcomes data out to at least 24 months[35]. Non-surgical, non-pharmaceutical interventions appeared to have some beneficial effect on long-term weight loss. However, gaps in the evidence remain concerning strategies that successfully improve PA recommendation adherence in order to encourage weight loss maintenance and attenuate the health risks attributable to obesity.

Physical activity health benefits and risks of sedentary behavior

Regular MVPA is associated with several beneficial health outcomes beyond weight control including musculoskeletal, cardiovascular, and psychological benefits[6-

11, 36-40]. PA has been shown to lower risks for CVD events so that increased PA participation was associated with decreased relative risk for CVD events including stroke and myocardial infarction[7]. A systematic review investigating the relationship between PA and several health markers found that PA improved cardiovascular health outcomes even in individuals with high BMI[36]. Other work has found improvements in glycemic control in individuals with type 2 diabetes associated with increased PA even when weight was unchanged[8]. Other work identified walking a mile on average per day to be associated with slower bone loss rates in post-menopausal women [10]. Finally, PA has been shown to relieve depression symptoms and stabilize mood in both clinically depressed and non-clinical populations[9].

Although the benefits of regular PA are fairly well known, the majority of American adults do not achieve recommended levels of weekly PA. According to the Centers for Disease Control and Prevention (CDC) investigations using data from the 2013 Behavioral Risk Factor Surveillance System (BRFSS), only 31% of adults achieve the recommended levels of PA: 300 minutes of moderate PA or 150 minutes of vigorous PA per week [41]. As improvements in technology have changed transportation, home, and work environments, sedentary time has increased around the world. Americans across all ages tend to spend an average of 7-8 hours per day engaged in sedentary activities[42].

Increases in the amount of time spent sedentary, that is sitting primarily at home, work, or in transit are associated with increased risks of several disease as well as mortality[43]. Increased sedentary behavior is independently associated with an increased risk for CVD and high BMI. Research using data from the Women's Health Initiative also found that sedentary behavior appears to modify the effect of BMI on CVD outcomes so that women with a BMI greater than 25 kg/m^2 and reported long periods of sedentary behavior had the highest rates of CVD events[44]. Due to the benefits of regular PA as well as the health risks of sedentary behaviors, encouraging regular PA and decreasing sedentary time to encourage both weight loss and healthy lifestyle have been promoted by US Department of Health and Human Services in the Physical Activity Guidelines for Americans[45].

Physical activity interventions

The low prevalence of individuals regularly achieving sufficient PA as well as the high prevalence of sedentary lifestyle have led to numerous PA interventions[46]. These include community, worksite and individual programs that have had modest success in producing higher PA achievement in adults.

Community and workplace environments are two domains identified for intervention development and delivery. Community level work offers the potential to reach large populations. These interventions often incorporate public flyers and advertisements, mailed information, in-person instruction, and exercise groups conducted throughout the community [47]. One successful intervention targeting older adults was implemented through community centers throughout the Seattle area [48]. Elderly adults were randomized to either participate in a PA class, a general health promotion class, a class covering both topics, or a no-class control group. PA was measured using self-report questionnaire and 6-minute walk objective measure. Those in the PA class and the combined PA and health promotion class groups had higher reported PA scores based on the Physical Activity Scale for the Elderly (PASE) (Mean Difference = 0.08 95%CI: 0.01, 0.15) and more steps taken during walking measurement (Mean Difference= 28.4 95% CI: 6.7, 50.1) than the no PA groups at 18-month follow-up. Authors noted no significant differences between the PA and the combined class groups[48].

An example of a community based PA intervention involved recruiting and training members of predominately African-American churches throughout South Carolina. Volunteers were trained to teach PA skills along with healthy eating, and to implement PA activities including aerobics, walking, and chair exercise[49]. This intervention was modeled after the Transtheoretical Model of behavior change[50] and community-based participatory research[51] and allowed churches considerable freedom to adapt the program to their unique needs. Participants from 303 churches were recruited; 170 churches received the intervention and 133 churches received a delayed program as control sites. Moderate PA was measured via survey at baseline, 1-year and 2-year follow-up. No differences in PA were found between the groups at any of the measurement time points[49].

The differences in the above interventions depict the vast heterogeneity in design, delivery, target population, and efficacy between community-based PA interventions. Overall interventions appear to show modest improvement in increasing numbers of physically active adults. However, differences concerning reach of the intervention, defined communities, and other practical elements pose challenges for reproducibility and implementation[47].

Worksite based PA interventions have increasingly been explored due to the majority of American adults spending a large proportion of time in the work environment. Worksite interventions have focused on increasing PA through counseling, group and self-instruction, environmental changes and prompts, goal setting and incentives[52]. PA interventions implemented in the worksite have targeted reducing risks for obesity, CVD, and diabetes outcomes as well as improving fitness and increasing PA[52]. Similar to community-based interventions, a review of worksite PA interventions found substantial heterogeneity between intervention design and delivery as well as target outcome measurement[52].

One example of an intervention that focused on increasing MVPA using goal setting and incentives, support and encouragement from managers, and environmental prompts in the workplace found moderate success[53]. This group-randomized trial was conducted at twenty Home Depot stores throughout the U.S. and Canada. PA was measured at baseline and, 6-week and 12-week follow-up using self-report questionnaires and pedometers. The intervention group had higher odds of meeting MVPA guidelines of 30 minutes at least 5 days per week at 12-weeks than control group (OR: 2.17, $p<0.001$)[53]. Though successful, the short duration of this intervention suggests a need for longer follow-up as well as interventions in other types of worksites.

Another PA intervention conducted at the University of Minnesota, targeting transit employees and bus drivers utilized environmental changes by improving fitness facilities within the worksite as well as holding fitness classes and walking programs and competitions[54]. The group-randomized design utilized the bus garage as the unit of random assignment and 4 garages were assigned to either intervention or control[54]. Physical activity [MVPA and LPA], measured via accelerometry and self-report, resulted in no statistically meaningful differences over two years of the intervention[54]. These results highlight the difficulty of increasing PA for jobs that require long periods of sedentary time.

Interventions to increase LPA and decrease sedentary time using PA workstations have been examined more recently. These interventions have incorporated sit-stand desks, pedal machines, step climbing machines, and treadmill desks[55]. Though these studies have been efficacious at reducing sedentary time (-77 mins/workday 95% CI: -120, -35), health outcomes varied by trial and were not significantly changed[55].

Concerning obesity and weight gain prevention, these interventions have had only minimal non-statistically significant effects on weight outcomes[52]. The HealthWorks trial is one example of multi-component intervention targeting weight outcomes of office-based employees[56]. Six worksites were randomized to the intervention or the comparison groups. The PA intervention included offering pedometers, improving stair environments, and offering walking clubs and competitions at work. This intervention had no statistically significant differences in weight outcomes between intervention and control groups at 2-year follow-up[56].

Individual-level PA interventions have been delivered via group, face-to-face, over the phone, and self-directed interventions. Overall individually based interventions appear to be moderately effective at increasing PA[57]. An analysis of individually framed cognitive and behavioral PA interventions estimated an over all increase in PA in treatment compared control groups in 206 trials[57]. Often, as with the community and worksite domains, individual PA interventions have been combined with dietary intervention components to improve various health outcomes, including obesity. On one hand, individual-level interventions have had the most success in reducing weight. However, their reach is much smaller, and the interventions more intensive, with effective programs incorporating both PA and nutrition behavior change segments to effect weight change[35].

The Look AHEAD study is one example of a multi-site individually based behavioral weight loss intervention to decrease obesity-related health risks[58]. The recruited population was highly sedentary, so that participants were encouraged to achieve a relatively modest final goal of 175 mins/weekly PA through home-based resistance training activities. The intervention consisted primarily of group and individual didactic sessions that discussed behavioral strategies to improving diet and PA. PA was assessed at baseline and 1-year follow-up via questionnaire for 2,221 participants. Individuals randomized to the lifestyle group increased leisure-time PA an average 784 kcal/wk ($p<0.001$) [58]. Further, percent change in leisure time PA was correlated with increases in objectively measured fitness ($r=0.20$, $p<0.001$) for 1027 individuals in the intervention group [58].

Physical activity maintenance

Unfortunately, regular PA following active intervention periods tends to decline over time. Bryan and colleagues found that in a twelve-month trial to increase PA in middle-aged adults, those in both the exercise intervention and the comparison group increased PA in the first 6 months of the trial and then leveled off between 6 and 12 months[59]. Though the intervention was effective at increasing self-reported PA, the 12-month cut point limits conclusions and understanding concerning PA changes or continuation after 12 months. When follow-up periods have been extended to 24 months, additional decline in PA has been observed [60]. However, Hall and colleagues found that following a PA intervention of older veterans consisting of telephone counseling sessions and monthly phone reminders over a 12-month period, 24-month PA levels still exceeded baseline levels[60]. Though these findings are promising, the research team also found that those who experienced the greatest decline in endurance PA level between the 12- and 24- month follow-up were those that were achieving the highest levels at 12 months[60]. This finding poses a practical challenge to weight loss interventions that recommend PA maintenance of achieving 250-300 minutes of MVPA weekly for sustained weight loss maintenance. Additionally, there are threats to validity with self-reported PA, such as over reporting due to self-presentation bias[61]. Exploration into decreasing sedentary time as an alternate maintenance strategy, and possibly lowering physical demands of the behavior, may have effects on adherence that are worth investigating. In order to better support this PA recommendation, more insight about PA maintenance and its relationship with weight control following active weight loss is imperative and requires theoretical insight.

Behavior change maintenance: Current theories and theoretical model

One issue challenging successful long-term behavioral maintenance achievement following initial behavior change may be the lack of long term evaluation following interventions and a shortage of behavior maintenance theories that have been tested[62]. Common behavior change theories are based on decisions to make initial behavior changes; however these theories are not always appropriate for extrapolation to maintaining or continuing behavior once the change has been made [63]. The health belief model, theory of planned behavior, theory of reasoned action, and social cognitive theory are examples of common behavior change theories that focus primarily on precursors to making the change[64]. These precursors, which differ, depending on the theory used, typically emphasize cognitions about self-efficacy to perform the behavior, perceived values and norms, and expectations that influence motivation to engage in behavior change prior to initiation. Rothman argues that drivers of behavioral maintenance are based on one's satisfaction with the results of the initial behavior change, costs to continue engagement in the new behavior, previous experience with the behavior, and personality traits[65]. More recently, Kwasnicka and colleagues have posited several themes common to behavioral maintenance theories that may be necessary to progress from initial behavior change to habituation as well: maintenance motives, self regulation, resources, habits, and social and environmental influences[62]. This dissertation examined several of these themes in regards to PA and weight loss maintenance.

In regard to PA specifically, Kahlert argues that lapses and recovery must also be evaluated together to adequately characterize PA maintenance[66]. Importantly, this context recognizes that PA is a complicated behavior that is performed daily over a long period of time to benefit health. PA maintenance is an ever-evolving process that may not be adequately captured with repeated measures at finite intervals. By following PA behavior more frequently over long periods of time, investigations can better characterize PA maintenance. In their behavioral theory of physical activity maintenance (PAM), Nigg and colleagues also suggest that PA continuation and the risk for relapse over time are situated within an individual's personal context[67]. The PAM framework posits that PA continuation is dependent on psychological factors that are directly influenced by contextual elements including life events and the environment[67]. These frameworks are necessary to set up the contextual foundation and theoretical structure for exploring the relationship of PA adherence and successful weight maintenance, which also results from a complex series of behaviors that include PA continuation.

This dissertation attempts to focus on the behavioral demands of maintenance, as proposed by Rothman and others[65], by examining weight outcomes and PA adherence from a weight loss intervention cohort that recommends high levels of MVPA, and from a worksite-based LPA intervention with a lower intensity PA recommendation. Aim 1, *identify changes in weight following a lifestyle weight loss program by examination of the impact of physical activity in the context of life events on those changes,* characterizes broadly the impact of PA continuation on weight loss maintenance using themes from behavioral weight loss research, maintenance theory proposed by Rothman and the PAM framework. By examining PA achievement as a potential mediator of the effect of the occurrence of life events on weight change, Paper 1 improves understanding about the relationship between life events, PA and weight loss maintenance. Further, by accounting for life events during weight loss and maintenance phases, this analysis also explores how PA participation modifies the association of these outside stressors on relapse or weight gain [67]. Within this context, the achieved PA level following weight loss intervention may instead show a protective effect against life stress during weight loss maintenance.

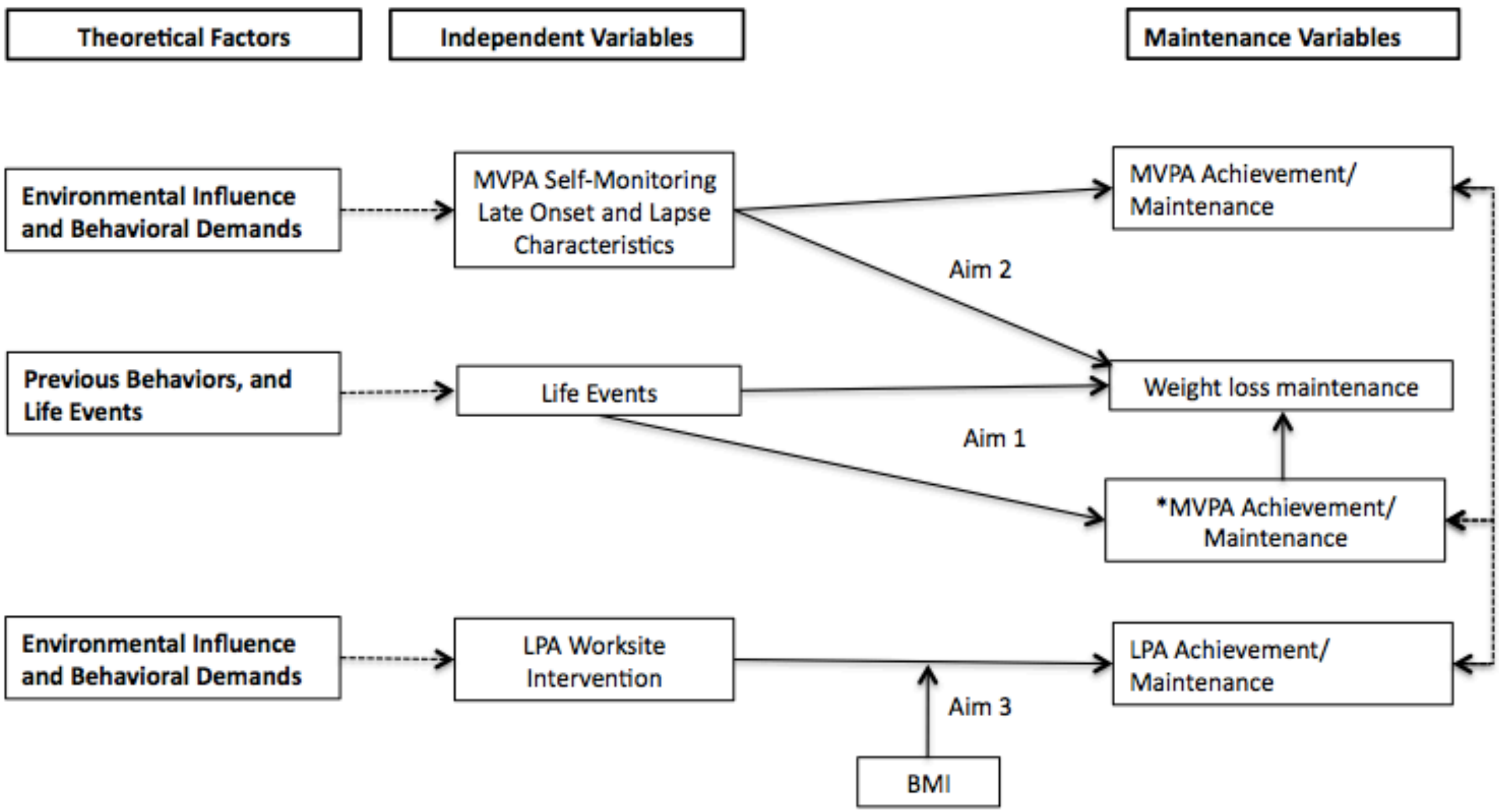
Aim 2, *examine the effect of physical activity tracking behavior during active weight loss intervention on moderate to vigorous physical activity achievement and maintenance, weight loss at 12 months (immediately following intervention), and weight loss maintained at 24-month follow-up*, defined and evaluated lapses or gaps in PA described by Kahlert as well as several self-monitoring gap characteristics. This paper offers a look at a particular opportunity for intervention improvement by evaluating the potential opportunity for one strategy of relapse identification. Behavioral maintenance themes that are explored include environmental influences and behavioral demands of purposeful MVPA. Kwasnicka and colleagues explain that cues from the environment may influence whether a newly developed behavior is successfully maintained[62]. In the Tracking study weight loss intervention, PA tracking logs serve as one cue for individuals. Interventionists reviewed logs and gave feedback regularly during the intervention. These logs might also serve as a more formal intervention-monitoring tool by program and intervention designers in the future. That is, interventionists may be able to identify earlier individuals who are at risk for behavioral relapse in need of an enhanced intervention through gaps in reporting from self-monitoring logs. By characterizing PA self-monitoring based on lapses and relapses and using these data to explore effects of PA achievement and weight maintenance, this investigation highlights potential mechanisms for intervention opportunities.

Aim 3, to *examine the association between baseline BMI and light intensity* *physical activity at baseline and 3-months during a light intensity physical activity worksite intervention,* looks further into the relationship between behavior change, behavioral demands and environmental cues in the workplace taking into account the personal characteristic of BMI. This third aim examines the success of a less physically demanding PA recommendation and intervention aimed at increasing LPA. By considering the long-term achievement of LPA goals, this analysis offers potential insight concerning behavioral demands of PA interventions. Further, the worksite environment within which the intervention is conducted helped to test the efficacy of a different type environmental cue from the PA self-monitoring logs explored in Aim 2.

Comparing MVPA recommendations from a weight loss intervention to LPA recommendations of a worksite intervention highlights some challenges and benefits of different PA recommendations with different behavioral demands within different contexts. These demands, external to the individual and imposed by the interventions, have previously been hypothesized to motivate individuals initially but may not persist over time, affecting maintenance success[63]. This concept, though not tested directly by any one of the aims was explored as a composite result of the three aims.

The following conceptual model (Figure 1) depicts the hypothesized relationships between PA continuation and weight loss maintenance explored in this dissertation. The solid lines depict the relationships directly evaluated in each aim. The dotted lines depict theoretical representation that the aims seek to clarify.

Figure 1: Conceptual Model



Summary of Significance and Innovation

This dissertation more closely investigates potential areas for improvement and tailoring of intervention design for improved PA continuation and weight control maintenance. The first manuscript utilizes a novel analysis method to more closely examine the relationship between external life events, MVPA achievement and weight. The second manuscript considers the association between self-monitoring characteristics and MVPA as well as self-monitoring and weight maintenance as a method for intervention improvement. The final manuscript examines the moderating effects of obesity status on LPA achievement within a worksite intervention, offering insight for intervention design and PA recommendations. Findings offer guidance to researchers and interventionists looking to improve continued regular PA for weight control as well as overall improved health outcomes.

CHAPTER 3

MANUSCRIPT #1: Life events, physical activity, and weight loss maintenance: Decomposing mediating and moderating effects on health behavior

Overview

This paper examined the relationship between the occurrence of life events (e.g. divorce, marriage, job change or loss, death of a relative, etc.), MVPA achievement and weight loss maintenance success following completion of a lifestyle weight loss intervention. Although adherence to high MVPA has been associated with better weight loss maintenance, this analysis attempted to clarify the individual and joint effects of significant life events and MVPA on weight following a behavioral weight loss trial. Data from the Tracking Study weight loss trial were utilized. Men and women residing throughout the Minneapolis-St. Paul, MN metropolitan area were recruited, randomized, and followed from July 2012 to September 2015. A four-way decomposition model to assess mediation and moderation was used to examine the effect measure modification and mediation between life events and MVPA achievement on 24-month weight. Independent variables were occurrence of life events (. >=1 life events vs. 0 life events) reported at 12 months as well as MVPA achievement (<2500 kcal vs. >=2500kcal) reported at18 and 24 months. The outcome was weight measured at 24 months. Using 18 month MVPA, the total effect of life events and MVPA on weight was estimated to be 1.36 kg (95%CI= 0.01, 2.70 p=0.05) and 1.63 kg (95%CI= 0.30, 2.96 p=0.02) in the model using 24 month MVPA. The controlled direct effect (CDE) of life events on 24-month weight was larger than the estimated total effect in models accounting for 18-

month MVPA (β =2.39 kg 95%CI= 0.31, 4.48) and 24-month MVPA (β =2.31 kg 95%CI= 0.29, 4.33). All other interaction and mediation estimates were not statistically significant at either time point. The total effect of life events and high MVPA at 18 months and 24 months were statistically significantly associated with weight. Findings suggest that effects of life events and MVPA on weight loss maintenance should be considered separately when considering weight loss maintenance and designing interventions to prevent weight regain.

Introduction

Researchers have identified regular moderate to vigorous physical activity (MVPA) as a common behavior in those who have been successful at preventing weight regain [31, 33]. One reason that consistent MVPA may be important for sustained weight loss is due to the influence of PA on stress and mood. PA has been shown to relieve depressive symptoms and stabilize mood in both clinically depressed and non-clinical populations [9]. Additionally, PA has been shown to improve mood and ability to cope with life occurrences including daily stress, divorce, legal issues, job loss or change, and deaths [68-70]. Due to evidence that supports the association of stress and depressed mood (which may co-exist with significant life events) with weight gain [71, 72], exploration into the relationship between life events, PA, and weight maintenance is necessary.

During the maintenance phase following weight loss programs, when intervention support for weight loss behaviors decreases, individuals may be at higher risk for weight gain. Under some circumstances, weight may be gained due to stress or negative emotions [71] caused by a stressful life event [72]. The potential for MVPA to moderate post-intervention weight regain due to the occurrence of a variety of life events (Figure 3) has yet to be explored.

On the other hand, research into PA maintenance also suggests that individuals who have recently adopted or increased PA are at higher risk for disengagement and relapse due to stressful life events [73]. This risk for behavioral relapse due to the occurrence of life events following intervention is a common consideration in behavioral maintenance theory as well [62]. That is, the occurrence of stressful life events may decrease motivation or commitment to newly adopted PA, as hypothesized by Nigg and others [67], thus leading to weight regain mediated through decreased physical activity (Figure 3). In order to assess the relationship between MVPA, life events, and weight relapse following intervention, exploration that considers both potential scenarios of moderation and mediation of the effect of life events on weight by MVPA participation is necessary.

Recently proposed statistical methods allow for the assessment of mediation and moderation simultaneously [74]. This decomposition of mediating and moderating effects, proposed by VanderWeele, has thus far been used to examine the effects of genetic and physiologic exposures on health outcomes. However, it also has the potential to offer a unique and innovative way to explore the effects of health behaviors that may act as both mediators and moderators of health outcomes.

This paper takes a closer look at weight loss maintenance success, dependent on MVPA and life events, in a sample of adults following completion of a lifestyle weight loss intervention. Although adherence to high MVPA has been associated with better weight loss maintenance [31], this analysis attempts to clarify the individual and joint effects of significant life events and MVPA on weight following a behavioral weight loss trial. We hypothesized that *the total effect of greater reporting of life events on weight within a lifestyle weight loss intervention will be influenced by individuals' physical activity levels during the maintenance phase*. Using this decomposition method we further expected that *a portion of the effect of reported life events on weight following a behavioral weight loss intervention will be moderated by physical activity level during the maintenance period*, such that individuals who participate in higher levels of physical activity will weigh less at 24 months despite life events experienced (Figure 2). Finally, *a portion of the effect of reported life events on weight following a behavioral weight loss intervention will be mediated by physical activity during the maintenance period*, such that the occurrence of significant life events will lead to increased weight through low participation in MVPA (Figure 3).

Methods:

Study Design and Randomization:

In order to assess differences in life events and the association with MVPA and weight loss maintenance, data from a randomized controlled weight loss trial were utilized. The Tracking Study was a three-arm randomized trial comparing the efficacy of self-weighing prescriptions during a behavioral weight loss intervention on weight and psychological outcomes over 24 months [12].

Individuals were recruited, randomized, and began the intervention in three waves staggered 6 months apart beginning in July 2012. Participation in the final wave concluded in September 2015. Detailed information regarding the Tracking Study has been published elsewhere [12]. A standard behavioral weight loss intervention was conducted for the first 12 months of study enrollment, followed by a 12-month measurement-only maintenance period. Participants completed questionnaires and anthropometric measures at baseline, 6-month, 12-month, 18-month, and 24-month time points.

Men and women residing throughout the Minneapolis-St. Paul, MN metropolitan area were enrolled between July 2012 and August 2013. Eligibility criteria required that participants have a BMI between 25-40 kg/m^2, have access to home wireless internet, have no recent weight loss greater than 10 pounds or history of bariatric surgery, and no history of significant physical or mental health concerns, including binge eating disorder. Women could not be pregnant or breastfeeding, or have plans to become pregnant for the 24 months of the study [12]. A total of 339 individuals were enrolled in the Tracking Study.

Life Events

In the decomposition model, a life events variable was treated as the exposure of interest. Life events were measured at baseline, 12-month, and 24-month visits using the Life Experiences Survey [75]. This survey assesses 24 different types of life events, including marriage, death of spouse or close family members, divorce, job loss or change, and change of residence, retrospectively over the 12 months prior to administration. Although participant responses tend to fluctuate over time, the measure has shown satisfactory reliability (r=0.63-0.64) over 6-week test-retest evaluation [75]. A binary variable with cut points for number of life events experienced as reported at the 24 month evaluation (occurring in the 12 months prior to that administration) was calculated. Individuals were categorized and compared using a classification of no life events (0 life experiences reported) and some life events (≥1 life experiences reported). In order to adjust for previous behaviors and experiences during the active weight loss phase, total number of life events, reported during the active weight loss phase, measured at 12-months, was included as a covariate.

Physical Activity

In this analysis, MVPA was the mediator/moderator of interest. PA was self-reported by all participants using the Paffenbarger Activity Questionnaire (PAQ) at baseline, 6, 12, 18 and 24 months [76]. This questionnaire assesses respondent's PA in the previous week in both closed and open-form questions. Open-form activity responses are categorized into light, moderate and vigorous PA, using self-reported duration and researcher-coded intensity to estimate calories spent participating in the various PA intensities during the previous week. Additionally, amount of walking and stair climbing are specifically assessed in two separate questions [76, 77]. Responses to these questions are incorporated into a total caloric expenditure calculation. The estimated energy expenditure calculated from this questionnaire was validated against VO_2 maximal output, a measure of physical fitness, and found to have acceptable validity (r=0.60) [77]. A binary variable indicating high levels of MVPA based on weekly calorie expenditure by all activities (excluding light physical activity) was calculated from the PAQ. Estimates were defined as low MVPA (<2500 kcal) and high MVPA (≥2500 kcal). This cut point has been defined in previous work into MVPA recommendations required for successful weight gain prevention following weight loss [78-80].

Weight

The primary outcome for this analysis was weight measured at 24 months following an active weight loss intervention. Trained staff measured weight at all assessment visits. Weight in kilograms was treated continuously. Weights at baseline and 12 months (the end of active intervention) were included in the models to account for prior weight change during active intervention.

Covariate Assessment:

Covariates included self-reported demographic characteristics collected at baseline: gender, race/ethnicity, educational attainment, marital status, and age calculated from date of birth. Due to the demographic background of the sample, race/ethnicity was treated as a binary covariate (white/other) as well as education level (college degree or more/less than a college degree), marital status (married/other), and gender (male/female). Age was treated as a continuous variable as well as baseline weight and physical activity expenditure (measured by the PAQ).

Dietary measures were collected using the self-reported Dietary History Questionnaire-II [81]. This online questionnaire estimates caloric intake and has been validated using 24-hour dietary recalls (r=0.62-0.66) [82]. Diet measured at 12-months was used as a covariate in all models to account for weight status associations with calorie intake.

Analysis:

Decomposition analysis:

A four-way decomposition model to assess mediation and moderation, developed by VanderWeele [74] was used to examine the proposed hypotheses. The hypothesized effect measure modification between life events and MVPA achievement on 24-month weight are visually depicted in Figure 2. The mediation mechanism, in which life events affect weight both independently and through MVPA achievement, is shown in Figure 3.

Using this method, the total effect of life events and high MVPA on weight was decomposed into four parts. The first component, the controlled direct effect (CDE), estimated the portion of the effect of life events on weight controlling for MVPA. This component is the independent effect of life events alone on weight. The second component, the reference interaction (INT_{REF}), estimated the interactive effect of life events and high MVPA on weight. The third component, the mediated interaction (INT_{MED}), estimated the portion of the effect of life events and high MVPA on weight that was both mediated and moderated. The fourth and final component in this analysis, the mediated main effect or pure indirect effect (PIE), accounted for the portion of the effect of life events on weight that is mediated through reported MVPA [74]. Figures 4a-d illustrate these four components and the relationships they represent.

Regression models, conditional on covariates were specified using PROC NLMIXED in SAS version 9.4 (Cary, NC). Code provided by VanderWeele was used to estimate the CDE, the PIE, and the INT_{MED} and the INT_{REF} [74]. The total effect of life events on 24-month weight, our main hypothesis of interest, was computed by combining all four components. This method utilized the binary exposure variable (≥1 life events vs. 0 life events), the binary mediator (<2500 kcal vs. ≥2500kcal), and the continuous weight variable. Separate models assessed MVPA at 18 and 24 months to capture the effect of high MVPA at different time points within the maintenance period. All covariates were standardized to the mean and standard deviation prior to regression modeling.

To test the first sub-hypothesis the percent of the effect due to interaction was computed. Using this method, only additive interactions were assessed. The percent of the total effect that is due to interaction between high MVPA and life events was found by summing the INT_{REF} and the INT_{MED} over the TE [74].

To test the second sub-hypothesis, the percent of the total effect that is due to mediation was computed. The percent of the total effect of life events on 24-month weight that is mediated through MVPA was found by summing of the PIE and the INT_{MED} over the TE [74].

Results

Summary statistics for participants reporting each category of life events (≥1 life events vs. 0 life events) reported at 24 months as well as the baseline sample are provided in Table 1. Of the 339 individuals who were enrolled in the original study, 230 participants contributed complete data for this analysis. Pairwise comparisons examined differences between baseline characteristics of participants with complete data at 24 months to the sample that was excluded from this analysis for incomplete data. Those who were included in this analysis were older (48.2± 9.5 years vs. 43.1± 10.8 years; p<0.01), weighed less at baseline (93.9 ± 15.6 kg vs. 98.7 ± 13.5 kg; p<0.01), and had a higher proportion of married (0.72 ± 0.45 vs. 0.60± 0.49; p=0.03) participants than the excluded sample. No statistical differences in education level, race, gender, baseline physical activity, or condition were detected.

At 24 months, 52 participants reported having experienced no life events and 178 reported at least one life event in the past 12 months. Those who reported experiencing at least one life event during the maintenance phase had previously reported experiencing on average 2.9 (±2.1) life events during the active weight loss phase, while those who reported no life events during the maintenance phase had reported experiencing on average 1.9 (±1.6) life events during the weight loss intervention. Of those participants who reported experiencing no life events during the maintenance phase, the large majority was white (96%) and married (77%). These percentages were smaller in the group that reported experiencing life events (87% white, 70% married). Finally, those reporting no life events reported substantially more PA at 12-, 18- and 24-month time points compared to those reporting some life events: 2604.9 kcal (±2433.7) vs. 2017.1 kcal (±1635.8) at 12 months, 2459.1 kcal (±2260.6) vs. 1881.7 kcal (±1720.0) at 18 months, and 2618.0 kcal (±2158.4) vs. 1972.2 kcal (±1624.0) at 24 months (see Table 1).

Prior to decomposition, multi-variable linear regression models that assessed physical activity and life events independently showed that the effects of life events and MVPA at 18 months were not statistically associated with 24-month weight. However, when the model examined 24-month MVPA, both life events (β=1.42 kg SE= 0.68, p=0.04) and MVPA level (β =1.32 kg SE= 0.63, p=0.04) were independently associated with weight (Table 2). Interactions between life events and MVPA at both time points were not statistically significant; therefore, the interaction terms were excluded from subsequent models.

Results of the full decomposition analysis are found in Table 3. Using 18 month MVPA, the total effect of life events and MVPA on weight was estimated to be 1.36 kg (95%CI= 0.01, 2.70 p=0.05). This effect increased to 1.63 kg (95%CI= 0.30, 2.96 p=0.02) in the model for 24 month MVPA. The CDE of life events on 24-month weight was larger than the estimated total effect in models accounting for 18-month MVPA (β =2.39 kg 95%CI= 0.31, 4.48) and 24-month MVPA (β =2.31 kg 95%CI= 0.29, 4.33). All other interaction and mediation decomposition estimates (INTref, INTmed, PIE) were not statistically significant at either time point (Table 3).

The estimated proportion of the total effect attributed to the interaction appeared to be stronger with 18 month MVPA (-101%; CI= -285%, 83%) than with 24 month MVPA (-66%; CI= -199%, 57%). The estimated proportion of the total effect attributed to mediation was similar with 18 and 24 month MVPA (5%; 95% CI= -12%, 21% and 9%; 95% CI= -7%, 26% respectively). However, these estimates were very small and not statistically significant (Table 3).

Discussion and Limitations

The results of the decomposition support the main hypothesis: the total effect of greater reporting of life events on weight within a lifestyle weight loss intervention will be influenced by individuals' physical activity levels during the maintenance phase. The total effect of life events and high MVPA at 18 months and 24 months (during the maintenance period) were statistically significantly associated with weight. This is consistent with previous work examining separately the effects of life events [72] and MVPA [31, 33] on weight maintenance. However, these findings suggest further that when considering the effect of life events on weight loss maintenance, it is important to account for MVPA as well.

However, results of the decomposition were not statistically significant. This suggests that the first sub-hypothesis was not supported by this analysis. Nevertheless, though not significant, the percent interaction of life events and MVPA participation was an estimated -101% (95%CI= -285%, 83%) at 18 months and -66% (95%CI= -199%, 57%) at 24 months. Both interaction estimates at 18 and 24 months (INTref and INTmed), though not statistically significant, point to a negative interaction, which is suggestive of our hypothesis that those achieving a higher level of MVPA would gain less weight despite life events experienced. Figure 5 depicts this relationship using a composite variable created from the MVPA and life event binary variables. The mean weight at 24 months was lowest for the group experiencing no life events and reporting high levels of MVPA at 18 months and 24 months. The groups reporting high life events and high MVPA at 18 months and 24 months and reporting no life events and low MVPA 18 months and 24 months had similar 24-month weights.

Finally, the group reporting low MVPA and occurrence of life events had the highest average weight. This pattern suggests a sub-additive interaction in which the group who experienced life events and participated in low levels of MVPA had an average weight that was similar to the group who experienced life events and participated in high MVPA or the group that did not experience life events and participated in low levels of MVPA. These findings, though not statistically significant, indicate that either the occurrence of life events or low MVPA participation were associated with similar weight at 24-months. This suggests that low MVPA is as detrimental to weight maintenance as disruptive life events. However, the presence of both life events and low MVPA was associated with 24-month weight that was lower than expected, given the assumption that these two factors together would be most disruptive to weight management.

Additionally, the second sub-hypothesis was not statistically supported. The CDE, the effect of life events in isolation on weight controlling for any mediation or effect modification by MVPA, for estimates at 18 months and 24 months were statistically significant and greater than the total effects at both time points. This finding suggests that mediation of the effect of life events on weight gain through low MVPA achievement is unlikely. Further, these very small percentages and reasonably small confidence intervals suggest that very little of the total effect of life events on weight is mediated by MVPA in this sample. This is consistent with other work [72] indicating that life events occurring during the maintenance phase may cause significant weight gain, and efforts to mitigate these effects through interventions continue to be important.

This exploration is innovative in the use of a novel statistical method to elucidate the relationship between life events, MVPA and weight maintenance. The decomposition offers more information about the relationship between life events MVPA and weight than the traditional multivariate regression models reported in Table 2. Although a larger sample may be necessary to produce statistically detectible effects, the percent interaction appears to be stronger than the percent mediation in this instance. This suggests that MVPA achievement may be working as an effect modifier and does not mediate the effect of the occurrence of life events on weight maintenance. Future work with a larger sample will be imperative to confirm or rule out interaction effects.

The 24-month follow-up allows exploration of behavior change over a relatively long period of time following an active weight loss intervention. Future work should examine whether these same relationships interact during the active weight loss phase as well as other factors that might mitigate the effects of life events on weight. Successful weight loss maintenance is the outcome of a relatively complex set of maintained behaviors beyond MVPA that require further examination to fully understand. Similarly, life events impact many behaviors and factors that may influence weight. Therefore, this study may only offer narrow insights into the relationship between life events and 24-month weight. However, noting the relatively small number of participants who experienced no life events, intervention components to help mitigate the effects of life events will be important going forward as well.

There are several limitations that should be noted. First, the identification of the four component effects requires several assumptions regarding confounding. After covariate adjustment, this method assumes no other unmeasured confounding of the effects of life events on either 24-month weight or MVPA, as well as no unmeasured confounding of the effects of MVPA on 24-month weight. Finally, it is assumed that all recanting witness variables are included as covariates. That is, all confounders between MVPA and 24-month weight that are affected by life events have been measured and accounted for in the models. Each of these assumptions are described in more detail by VanderWeele and Vansteelandt [83] and Pearl [84].

Although multiple covariates were included in this analysis, the above assumptions are very strong and unmeasured confounding within this complex relationship of life events, MVPA and weight likely remains. For example, although diet was measured at 12 months via self-report, later dietary changes may act as residual confounders of the effect of life events on weight or physical activity on weight. Unmeasured variables, such as social support or habit formation that could confound the relationship between occurrences of life events on MVPA and/or weight at 24 months may also exist. There are several factors that may influence weight gain as well as MVPA following important life events including diet, drug and alcohol use, and mood. Future work that explores the role of these factors and their potential roles as mediators and moderators of both physical activity and weight gain is needed.

The potential for measurement error in the self-reporting of life events and MVPA is another limitation. It is plausible, that participants may incorrectly remember the time-window of these life events. In this case, fewer participants may have experienced life events in the past year, potentially introducing recall bias. Examining life events in shorter intervals in future work may help to address this issue.

Self-reporting MVPA may introduce additional measurement error. Previous work has suggested differential MVPA reporting dependent on weight status suggesting that individuals with higher weight may over report MVPA[85]. At baseline and 12 months, approximately half of individuals in this sample were randomized to wear accelerometers for 7-days in order to assess the validity of this questionnaire. At twelve months, accelerometery measured MVPA was sufficiently correlated with the PAQ measure ($r=0.56$; $p<0.01$). However, future work using objective MVPA measurements will be important to improve this work. Further, the PAQ only assessed MVPA, thus no conclusions can be made regarding the role of light intensity physical activity.

Additionally this analysis method required complete data for effect estimation. Therefore, missing data from participants narrowed the available sample size considerably. Further, the large number of covariate parameters limited power to detect any small-decomposed effects. Imputation models were considered and resulted in similar findings; thus, only the complete data models were reported in this analysis. Future analyses utilizing a larger, more diverse sample may improve detection and should be explored.

Separate models for each time point allow only qualitative comparisons between models to be made. The inability to perform statistical tests across MVPA time points is a limitation. Separate analyses for the 18-month MVPA and 24-month MVPA do not offer insight into change in MVPA from 18 months to 24 months. While this analysis method may be important to behavioral research, temporality and the effects of mediator changes over time will be important to consider moving forward.

The total effect of life events and MVPA on weight maintenance was fairly small, though statistically significant. As mentioned previously, this small total effect is likely another reason the decomposed effects were non-significant. However, this sample had a large proportion of white, married, and college-educated adults who may have social and economic resources that offer protection from the detrimental effects of life events on weight during weight loss maintenance. Further, when examining those who experienced no life events, the number of non-white, non-married individuals was even smaller. Future work should consider examining this relationship of life events, MVPA, and weight loss maintenance in ethnically diverse populations or populations with lower SES who may be likely to experience these life events more often.

Conclusion

This paper explores the use of a newly proposed statistical analysis method in behavioral health research. This method offers a unique and innovative way to explore the effects of behavior changes on health outcomes within the context of one's personal environment. Specifically, the 4-way decomposition offers new potential for examining the effects of health behaviors that may act as both mediators and effect modifiers of health outcomes in the same analysis. Although, little can be said about the interaction of life events and MVPA achievement on weight loss maintenance, our findings help to rule out mediation. This suggests that the effects of life events and MVPA on weight loss maintenance should be considered as separate effects when considering weight loss maintenance and designing interventions to prevent weight regain. More work is needed in larger and more diverse samples to more fully understand these decomposed effects. Further work that explores relationships between life events, MVPA and mood and well as other behaviors that may effect weight maintenance will also be important.

Tables and Figures:

Table 1: Weight, change in physical activity, caloric intake, previous life events and demographics for levels of life events during the maintenance phase

Characteristics	Baseline sample, n=339	No life events (reported at 24 months) n= 52	≥1 life events (reported at 24 months) n= 178
Baseline Weight mean, (SD)	95.5 kg (±15.1)	94.6 kg (±14.3)	93.8 kg (±15.9)
12-Month Weight	--	84.5 kg (±14.9)	85.9 kg (±14.9)
24-Month Weight	--	87.4 kg (±15.3)	89.5 kg (±15.5)
Baseline Physical Activity, measured by PAQ	1309.9 kcal (±1250.9)	1268.2 kcal (±1147.0)	1305.4 kcal (±1191.8)
12-month PA	--	2604.9 kcal (±2433.7)	2017.1 kcal (±1635.8)
18-month PA	--	2459.1 kcal (±2260.6)	1881.7 kcal (±1720.0)
24-month PA	--	2618.0 kcal (±2158.4)	1972.2 kcal (±1624.0)
Life Events, Number reported during active weight loss (measured at 12 months) , mean (SD)	--	1.9 (±1.6)	2.9 (±2.1)
Age, mean years (SD)	46.5 (±10.2)	48.5 (±9.7)	48.0 (±9.5)
Women, n (%)	220 (65%)	35 (67%)	117 (66%)
White, n (%)	293 (86%)	50 (96%)	155 (87%)
College graduate, n (%)	216 (64%)	31 (60%)	121 (68%)
Married, n (%)	230 (68%)	40 (77%)	125 (70%)
Weighing Assignment			
No weighing, n	116	19	58
Weekly weighing, n	109	15	63
Daily weighing, n	114	18	57

Table 2: Linear regression model of life events and MVPA on 24 month weight (kg)

		ß (SE)	*p*
Adjusted effects at 18 month PA	Life events (1 vs. 0)	1.28 (0.69)	0.06
	PA (< 2500 kcal vs. ≥2500 kcal)	0.93 (0.66)	0.16
Adjusted effects at 24 month PA	Life events (1 vs. 0)	1.42 (0.68)	0.04
	PA (< 2500 kcal vs. ≥2500 kcal)	1.32 (0.63)	0.04

**Adjustment variables include age, gender, race, education level, marital status, baseline and 12 month weight, baseline physical activity, baseline weight loss behavior self-efficacy, 12-month calorie intake, life-event frequency during active weight loss and randomization arm.*

Table 3: Decomposition model of life events and MVPA on 24 month weight (kg)

	ß (95% CI)	*p*
Adjusted effects of life events with 18-month PA		
Total Effect	1.36 (0.01, 2.70)	0.05
CDE	2.39 (0.31, 4.48)	0.02
INTref	-1.10 (-2.73, 0.53)	0.18
INTmed	-0.27 (-.77, 0.22)	0.28
PIE	0.33 (-0.17, 0.84)	0.19
Percent Mediation	5% (-12%, 21%)	0.58
Percent Interaction	-101% (-285%, 83%)	0.28
Adjusted effects of life events with 24-month PA		
Total Effect	1.63 (0.30, 2.96)	0.02
CDE	2.31 (0.29, 4.33)	0.03
INTref	-0.84 (-2.31, 0.64)	0.26
INTmed	-0.24 (-0.72, 0.25)	0.34
PIE	0.39 (-0.17, 0.95)	0.17
Percent Mediation	9% (-7%, 26%)	0.28
Percent Interaction	-66% (-199%, 57%)	0.31

**Adjustment variables include age, gender, race, education level, marital status, baseline and 12 month weight, baseline physical activity, 12-month calorie intake, life-event frequency during active weight loss and randomization arm.*

Figure 2: Effect of life events on weight loss maintenance modified by change in physical activity

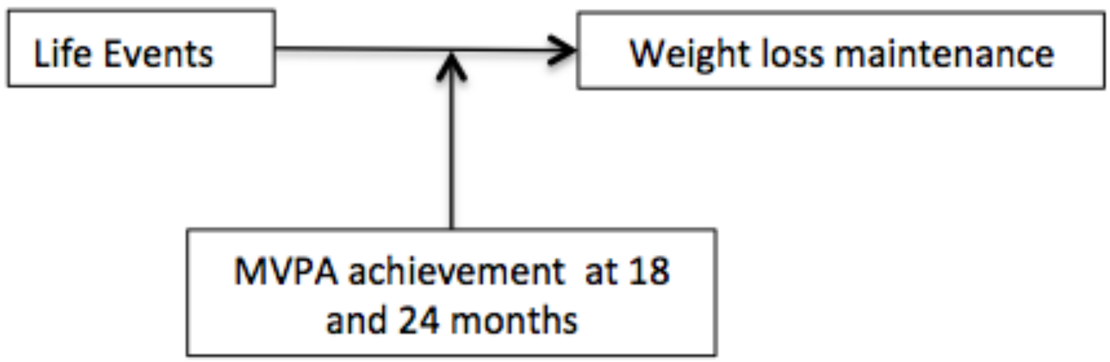


Figure 3: Effect of life events on weight loss maintenance mediated by change in physical activity

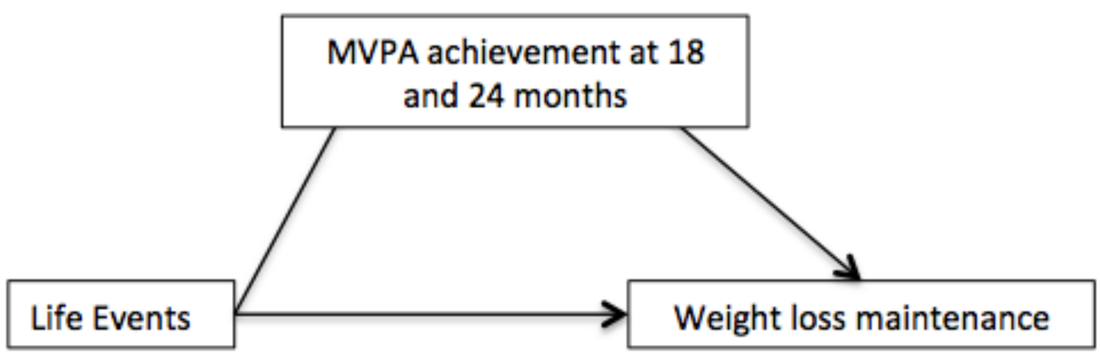


Figure 4: Graphical depictions of single components in decomposition

Figure 4a: Controlled direct effect of life events on weight

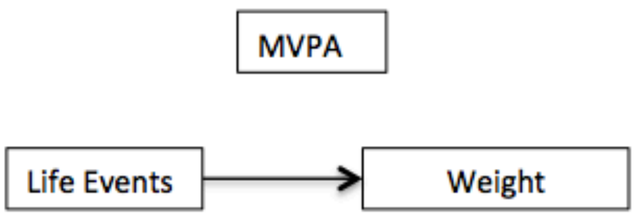


Figure 4b: Reference interaction effect of life events and MVPA on weight

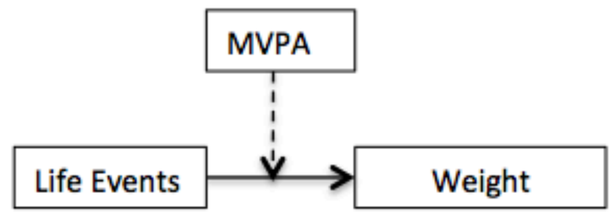


Figure 4c: Mediated interaction effect of life events and MVPA on weight

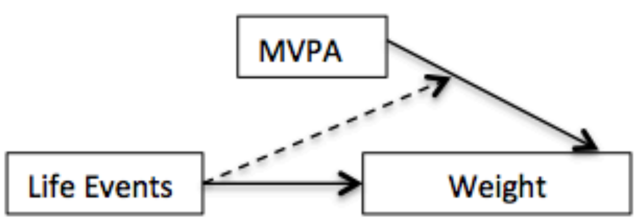


Figure 4d: Pure indirect effect of life events on weight mediated through MVPA

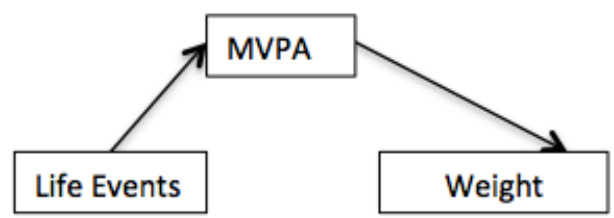
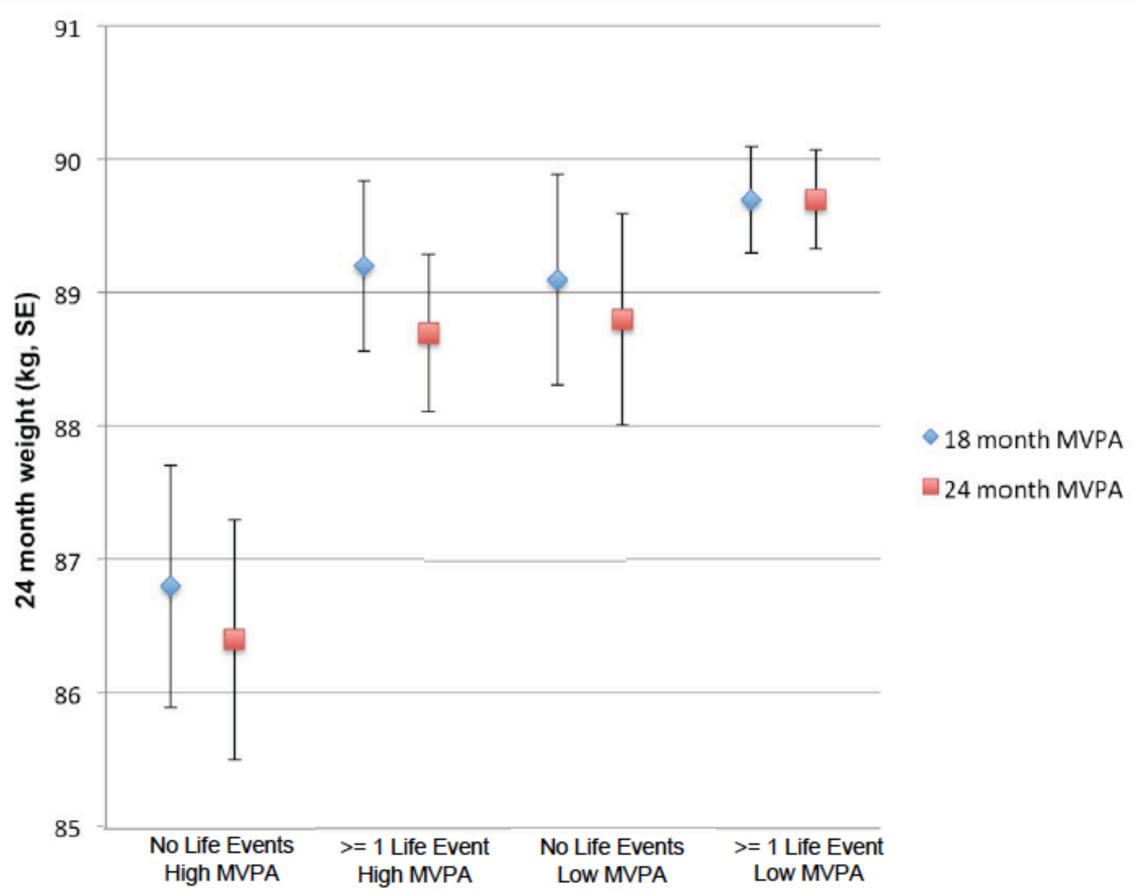


Figure 5: Mean 24-month weight associated with life event and MVPA achievement composite variables



**Adjustment variables include age, gender, race, education level, marital status, baseline and 12 month weight, baseline physical activity, 12-month calorie intake, life-event frequency during active weight loss and randomization arm.*

CHAPTER 4

MANUSCRIPT #2: Characterizing self-monitoring behavior and its association with physical activity and weight loss maintenance

Overview

Using behavior-tracking logs during weight loss interventions to identify individuals in need of supplemental support is one strategy that may result in increased behavior adoption and maintenance. Reviewing gaps in physical activity and dietary self-monitoring logs may help interventionists to identify individuals who are successfully adopting MVPA or who are demonstrating signs of behavioral disengagement during active intervention. The purpose of this study was to examine the associations of different PA tracking characteristics during an active weight loss intervention with moderate to vigorous physical activity achievement and maintenance, weight loss at 12 months (immediately following intervention), and weight loss maintained at 24-month follow-up. Secondary data analysis was conducted using data from the Tracking Study, a trial comparing the efficacy of weight-tracking frequency during a lifestyle weight loss program. Participants were recruited from the Minneapolis-St Paul metropolitan area beginning in July 2012 and ending in August 2013. Self-monitoring logs for both diet and physical activity were used to define eight self-monitoring characteristics: total number of tracking gaps, average length of tracking gaps, late onset of tracking, and week of first gap in behavior tracking. Four specific gap lengths were also examined. Self reported PA, and staff-measured weight was reported at baseline, 6-, 12-, 18- and 24-month time points. General Estimating Equation (GEE) modeling was used to examine the association between physical activity self-monitoring characteristics and reported MVPA participation and weight measured at 12-month and 24-month follow-up. Additional models examined the association of the following specific gap sizes on MVPA and weight as well: short (1-4 weeks) gaps, medium length (5-8 weeks) gaps, long length (9-12 weeks), and extra-long length (>12 weeks) gaps in PA self-monitoring. Results showed that participants who were not tracking as early as the second week of the intervention reported less MVPA and had higher weights at 12 months and 24 months compared to those who began tracking earlier. Further, ongoing consistent tracking of MVPA was statistically associated with increased reported MVPA and lower weight. Increases in total number of gaps as well as average gap length were associated with a decreased MVPA achievement. Results for specific gap lengths showed that increased frequency of short gaps in PA tracking and dietary tracking were statistically associated with higher weight at 24 months. Finally, increases in extra-long (>12 weeks) length gaps PA and dietary self-monitoring were statistically associated with a decreased reporting of MVPA and increased weight. Monitoring physical activity and dietary tracking logs should be considered as a tool to identify individuals who show signs of behavioral disengagement early in the intervention process in order to improve physical activity participation and weight maintenance.

Introduction

The high prevalence of overweight and obesity in American adults poses a risk to both individual and population health due to the association of excess body weight with mortality and morbidity [17]. Higher rates of cardiovascular disease, cancer, metabolic syndrome, and other chronic diseases have all been found to be associated with obesity [3], impacting quality of life and healthcare costs in the United States and other developed countries. Fortunately, there is evidence that moderate weight loss by obese individuals is sufficient to ameliorate the risk for many of these diseases and show beneficial health outcomes [22, 23]. Behavioral weight loss interventions have shown some success in helping individuals to lose weight [24], and more individuals are attempting to lose weight [2]. Despite these positive intervention outcomes, weight loss maintenance continues to be a challenge. Researchers have identified continued high levels of physical activity (PA) following active weight loss periods as one strategy associated with weight re-gain prevention [31, 33]. However, effective strategies that promote regular moderate to vigorous physical activity (MVPA) in order to encourage weight loss maintenance are still needed.

Furthermore, regular MVPA following active intervention periods tends to decline over time. Bryan and colleagues found that in a 12-month trial to increase MVPA in middle-aged adults, those in both the exercise intervention and the comparison group increased MVPA in the first 6 months of the trial and then leveled off between 6 and 12 months [59]. When follow-up periods have been extended to 24 months, further decreases in MVPA has been observed [60]. This trend suggests a need for improved intervention design and monitoring that results in sustained behavioral effects.

Using behavior-tracking logs to identify individuals in need of supplemental support is one strategy that may result in increased behavior adoption and maintenance. Tracking dietary intake and PA using daily diaries has previously shown to be an effective weight loss tool [86]. In addition to increasing behavioral awareness for those participating in interventions, this tool presents opportunities for interventionists to monitor participant progress and offer feedback and support. When feedback is given frequently about behavioral progress, researchers have found that individuals tend to be more adherent to diet and PA goals [86]. However, these findings have been limited primarily to 6-month and 12-month studies [87]. Additionally, although behavioral self-monitoring has been identified as a correlate of successful weight loss maintenance [88], the impact of self-monitoring on weight loss maintenance has been limited to broad and self-reported adherence measures [87].

Recent technological advancements offer easier and more convenient ways for interventionists to survey individuals' weight loss behavior tracking through websites and mobile applications. These websites and applications designed for tracking PA and diet offer convenient and accessible data capture and storage. Individuals can more easily track behaviors using cell-phone applications that they can access anywhere. These behavioral tracking applications have differing implications for intervention depending on the behavior of interest. With dietary tracking, those who do not track dietary intake are likely not being fully adherent to recommendations; however, they are assumed to be engaging in some sort of dietary intake[89]. Conversely for PA tracking, it is assumed that individuals who are not self-monitoring PA are also not engaging in any MVPA at all[87]. Therefore, electronic data capture methods may make it easier for interventionists to identify individuals who are successfully adopting MVPA or are demonstrating signs of behavioral disengagement following adoption. This process, of identifying individuals through gaps in electronic tracking logs has the potential to better support PA initiation or lapse recovery in order to maintain high levels of MVPA over time and improve weight loss maintenance. However, indicators of behavioral engagement and adherence using self-monitoring adherence have yet to be examined.

In order to begin to evaluate this potential method for identifying individuals who show signs of behavioral disengagement during weight loss interventions, the association of PA self-monitoring characteristics with weight loss maintenance and long-term MVPA participation must first be evaluated. The purpose of this study was to examine the effect of physical activity tracking behavior during weight loss intervention on the following markers: MVPA, weight loss achievement post-intervention, and weight and activity maintenance, in order to inform efforts to enhance engagement in the intervention period before significant adherence lapses occur. We hypothesized that *later onset and greater frequency of gaps in of physical activity self-monitoring during intervention will be associated with lower reported physical activity levels measured at 12-month and 24-month follow-up*. Additionally, *later onset and greater frequency of gaps in physical activity self-monitoring during intervention will be associated with higher weight at 12-month and 24-month follow-up*.

Methods

In order to assess PA tracking patterns over time on PA participation and weight loss maintenance, secondary data analysis was conducted using data from the Tracking Study, a randomized trial comparing the efficacy of three different weight-tracking conditions during a non-pharmaceutical lifestyle weight loss program [12]. Participants were randomized to daily, weekly, or no self-weighing for the duration of a 12-month intervention with an additional 12-month measurement-only follow-up. Participants were recruited from the Minneapolis-St Paul metropolitan area in three waves beginning in July 2012 and ending in August 2013. Study participation lasted 24 months, with the final follow-up visits in September 2015. Study measurement visits occurred at baseline, 6-month, 12-month, 18-month, and 24-month time points. This study was approved by the University of Minnesota Internal Review Board.

The behavioral weight loss intervention included group lessons, activities, discussions, worksheets and handouts delivered by trained nutritionists at the University of Minnesota. Topics of each meeting included behavioral lessons such as goal setting, planning, and problem solving, as well as more specific nutrition and PA topics. Participants were instructed to set a goal of achieving at least 250 minutes of purposeful MVPA per week. Further details on the original study can be found elsewhere [12].

Population

Participants were required to be between the ages of 18-64, reside within 50 miles of the University of Minnesota, and have a BMI between 25-40 kg/m^2 [12]. Additionally, participants had to verify that they had home wireless internet for scale connectivity, had no recent weight loss greater than 10 pounds, no history of bariatric surgery, and no significant health concerns. Women could not be pregnant or breastfeeding, and could not be planning to become pregnant for the duration of the study [12].

A total of 339 men and women were enrolled in the study. This cohort was 64.9% female, 46.5 (±10.2) years of age on average, and 86.4% white. Further, 67.9% of participants were married or partnered, and 63.7% had at least a college degree. A full description of the study sample and intervention protocol can be found elsewhere [12].

Exposures

Behavior Self-Monitoring

Physical activity and dietary tracking logs were kept during the 12-month weight loss intervention. Self-monitoring logs were completed using paper diaries for participants in the no-weighing condition and a web-based and mobile tracking application LoseIt! (FitNow, Inc. Boston, MA) for those in the daily and weekly weighing conditions. Paper logs were collected at each group meeting and intervention staff recorded the number of days that PA and diet was tracked. For those using electronic tracking, the LoseIt! accounts were configured to email PA and dietary records directly to the interventionists each week. Interventionists then printed the records in order to record self-monitoring and give feedback to participants at the in-person group sessions. Participants were instructed to only include purposeful bouts of MVPA in their PA logs, so a primary reason for any gaps in PA tracking was the absence of engagement in MVPA.

Using the self-monitoring logs, study staff recorded the number of days that leisure time MVPA was tracked per week, as well as number of days that diet was tracked. When recording MVPA tracked for data collection, study staff did not count less exertive activities such as gardening or yard work as a bout of MVPA. Total adherence was defined by the total number of days or recorded self-monitoring during the 12-month intervention period. Eight behavioral characteristics were used to examine the association between PA tracking behavior and PA outcomes and weight. These included four self-monitoring characteristics: total number of tracking gaps, average length of tracking gaps, late onset of tracking, and week of first gap in behavior tracking. Four specific gap lengths were also examined. Tracking gaps were defined as ≥1 week of no activity logging. The total number of gaps for each participant was recorded as well as the length of each gap. Average length of the gaps for each participant was then calculated. Late onset of PA self-monitoring was defined as a binary variable. By the second week of the intervention, individuals who had zero days reported of PA self-monitoring based on their weekly logs were categorized as late onset self-reporting. Individuals who had at least one day of PA logged within that week were categorized as regular onset of self-reported PA tracking. Short gaps were defined as gaps lasting 1-4 weeks, about 1 month or less. Medium gaps were defined as 5-8 weeks, or about 2 months at most. Long gaps were defined as 9-12 weeks of no behavior tracking, or about 3 months at most. Extra-long gaps were defined as any gap lasting longer than 12 weeks. These definitions are similar to previous literature that examines the effects of long and short gaps of weight control behaviors on weight loss [90] and have been expanded to include more variability in this observational sample.

Dietary self-monitoring was tracked using the same logs as PA tracking and was also collected, reviewed and recorded by intervention staff at each group meeting. Gaps in dietary tracking were defined as zero logged calories for at least one week during the active intervention period. Due to similar and contemporaneous tracking of diet and PA, dietary tracking characteristics were defined in the same way as the PA self-monitoring characteristics: total number of tracking gaps, average length of tracking gaps, late onset of tracking, week of first gap, short gaps, medium gaps, long gaps, and extra long gaps in tracking. Separate models examining the association between dietary tracking behavior characteristics on weight were examined to account for any confounding that may impact weight change due to dietary self-monitoring.

Outcomes:

Physical activity

MVPA was measured at each time point by the self-reported Paffenbarger Activity Questionnaire (PAQ) [76]. The PAQ is comprised of both closed and open-form questions that assess PA over the past week. Both closed and open-form questions are used to measure PA caloric expenditure. Two separate questions assessed distance walked and flights of stairs climbed. Weekly kilocalorie (kcal/wk) expenditure from moderate to vigorous activities was calculated based on PAQ scoring [76]. This measure performed sufficiently in validation studies compared to VO_2 maximal output ($r=0.60$, $p<0.05$) [77]. For this analysis, MVPA was represented by the calculated continuous caloric expenditure variable (kcal/wk).

Weight

Trained staff using Tanita digital scales measured weights at baseline, 6-month, 12-month, 18-month, and 24-month visits. Two weights were taken for each participant, and weights were averaged together to give one weight. If the two weights differed by more than 0.5 kg, a third weight was taken and all three weights were averaged. For weight loss at 12 months, mean weight at 12 months, accounting for baseline and 6-

month weight, was compared across the different self-monitoring exposure variables. Similarly, 24-month weights, accounting for previous weight measurements, were compared across self-monitoring variables to capture weight change during the maintenance phase. Weight outcomes were treated continuously.

Covariates

Demographic variables were self-reported at baseline. They included age, gender, race, marital status and level of education. Race (white or other), marital status (married or not) and education level (college degree or less) were treated as binary variables. Treatment condition (daily, weekly, or no weighing) was also included in adjusted models and treated as a categorical covariate.

Analysis

Descriptive statistics for PA self-monitoring, reported MVPA calorie expenditure, weight change, dietary self-monitoring and demographic characteristics for the sample were generated using SAS version 9.4 (Cary, NC). General Estimating Equation (GEE) modeling was used to examine the association between physical activity self-monitoring characteristics and reported MVPA participation measured at 12-month and 24-month follow-up. Separate models were used to define the associations of increases in total number of gaps and average length of gap characteristics as well as late onset and week of first gap with reported MVPA. Models also examined the following specific gap sizes on MVPA achieved at 12-month and 24-month follow-up: short (1-4 weeks) gaps, medium length (5-8 weeks) gaps, long length (9-12 weeks), and extra-long length (>12 weeks) gaps in PA self-monitoring. The GEE model accounts for correlation of MVPA for each individual measured over time. An identity link function with a normal distribution was specified for the continuous MVPA outcome. Demographic variables were evaluated as covariates.

GEE models were also used in the analysis of the association of self-monitoring characteristics and weight at 12-month and 24-month follow-up. Similarly, a normal distribution with the identity link was specified. Due to the correlation between PA and dietary tracking measures (See Table 2), models assessing the association and self-monitoring of PA and diet were analyzed separately. Finally, models examining the interaction of dietary self-monitoring and PA self-monitoring characteristics on weight were also evaluated.

Results

Visual plots of PA and dietary self-monitoring of participants are shown in Figures 5a and 5b. Weeks are colored red (PA) or green (diet) to indicate self-monitoring that week. Weeks are colored grey to indicate no self-monitoring. Self-monitoring was first recorded and evaluated during the second week to allow participants to receive and become familiar with tracking logs. In the figure, individuals were sorted based on first gap in tracking, followed by adherence so that the most adherent participants (those with no gaps in tracking) are at the top and the least adherent (those who never participated in behavioral tracking) are at the bottom. In both figures self-monitoring appears to decline over the one-year weight loss intervention.

During the weight loss trial, mean weight decreased from 95.5 kg (±15.1 kg) at baseline to 90.3 kg (±15.9 kg) on average at 24 months, with no statistically significant difference by intervention arm [91]. Additionally, reported physical activity increased substantially from baseline (1309.9 kcal/wk ±1250.9 kcal/wk) to 12 months (2116.9 kcal/wk ±1827.7 kcal/wk) and then appeared to level off at 2132.3 (±1796.0) kcal at 24 months (Table 4).

Participants received directions on diet and PA tracking during their first intervention session and, on average, they began tracking both diet and physical activity within the first 2 weeks. Throughout the first year of intervention, participants had on average 3.7 (±2.6) gaps in PA tracking and 2.7 (±2.2) gaps in tracking of dietary behavior (r=0.59). Gaps in PA self-monitoring lasted an average of 11.6 (±15.4) weeks, while gaps in dietary self-monitoring lasted 11.0 (±15.1) weeks on average (r=0.91) (Table 4).

Self-monitoring and MVPA

The results of the GEE analysis of physical activity self-monitoring characteristics on 12- month and 24-month self-reported MVPA level are presented in Table 5. Late onset of PA tracking was associated with lower physical activity at both 12 and 24 months. Participants who were not tracking as early as the second week of the intervention reported 345.1 kcal/wk (SE=137.2; p=0.02) less MVPA at 12 months and 323.7 kcal/wk (SE=153.6; p=0.04) less MVPA at 24 months compared to those who began tracking earlier. Further, ongoing consistent tracking in the study (i.e., later appearance of the first gap in PA self-monitoring) was statistically associated with increased reported MVPA; with every additional week of consistent tracking, reported MVPA increased by 26.1 kcal/wk (SE=7.1, p<0.01) at 12 months and by 25.0 kcal/wk (SE=7.8, p<0.01) at 24 months.

Increases in total number of gaps scaled to 4 week increments were associated with decreased weekly MVPA achievement at both 12 months (-252.8 kcal, SE= 104.5, p=0.02) and at 24 months (-255.4 kcal, SE=123.2, p=0.04). A similar trend was seen with average length of gap so that as average gap length increased by 11.8 weeks (the inter-quartile range), reported weekly MVPA achievement decreased by 118.8 kcal (SE = 54.8; p=0.03) at 12 months and decreased by 153.5 kcal (SE= 56.8, p=0.01) at 24 months. Increases in short (1-4 weeks), medium (5-8 weeks), and long (9-12 weeks) length gaps were not statistically associated with MVPA achievement. However, these estimates are likely underpowered and appear to show an increasing dose response. That is, is the amount of reported physical activity decreases as gap length grows. Finally, extra-long (>12 weeks) length gaps were statistically associated with decreased reporting of weekly MVPA by 472.8 kcal (SE= 376.1, p<0.01) at 12 months and 544.3 kcal (SE= 124.5, p<0.01) at 24 months.

Effect measure modification by gender was tested for each self-monitoring variable and was not statistically significant. Although dietary gaps in tracking were not expected to be associated with MVPA, analyses examining the association of the corresponding dietary self-monitoring characteristics were conducted in order to examine overall tracking behavior on MVPA. No statistically significant findings were observed with the exception of average gap length (Table 6). This was likely due to the high correlation between dietary and PA tracking average gap lengths (r=0.91; See Table 7). All other correlations between PA and dietary tracking variables are reported in Table 7.

Self-monitoring and Weight

Results of the GEE analysis investigating the association between PA and dietary self-monitoring behaviors with 12- and 24-month weight outcomes are reported in Tables 8 and 9. Due to the correlation between dietary tracking and PA tracking variables, independent models examining PA and dietary tracking separately were reported as well as a joint model. Effect measure modification was tested for all joint models and reported when present.

In the individual model, late onset of PA tracking was associated with weight at 12 months (RD= 3.0 kg, SE=1.3 p=0.02). However, dietary tracking was not associated with weight at 12 months. These trends were similar when evaluating weight at 24 months. Again, late PA self-monitoring was significantly associated with increased weight, while dietary self-monitoring was not. The interaction between late onset of PA and dietary self-monitoring could not be evaluated because no participants were categorized as engaging in late dietary tracking but not late PA tracking. However the joint model suggests that after controlling for late onset of dietary tracking, late onset of PA was still statistically significantly associated with increased weight.

Week of first gap for both PA and dietary tracking evaluated independently were statistically associated with weight at 12 months. Suggesting that as the week of the first gap in PA tracking increased, weight at 12 months decreased by 0.2 kg (SE=0.1, p<0.01). These results were similar for dietary tracking. Results of the joint model show the effect modification between week of first gap in PA and dietary tracking to be statistically significant as well. Models evaluating week of first gap and weight at 24 months resulted in similar findings.

At 12 months, increases in total number of gaps in PA self-monitoring (β=2.6, SE=1.0, p<0.01) and dietary self monitoring (β=2.2 , SE=0.9, p=0.02) were individually associated with weight at 24 months. When both PA and dietary tracking gaps were examined in the joint model no association between weight and total gaps resulted. At 24 months findings for PA self monitoring gaps (β=3.2, SE=1.0, p<0.01) and dietary self monitoring gaps (β=2.9, SE=0.9, p<0.01) were similar. The effect measure modification between dietary and PA self monitoring on weight was significant (β=2.8, SE=1.5, p=0.05)at 24 months as well. Average length of gap of PA tracking and dietary tracking were not statistically associated with weight at 12 or 24 months (See Tables 7 and 8).

Results for the specified gap lengths are reported in Tables 8 and 9. Increased frequency of medium length gaps in PA tracking(β =2.6, SE=1.0 p=0.01) were statistically associated with weight at 12 months and 24 months (β=2.8, SE=1.0 p<0.01). The individual model assessing frequency of medium dietary tracking gaps resulted in no statistically significant association between gaps and weight, nor did the interaction between medium dietary and PA tracking gaps. Frequency of short gaps in PA tracking (β=0.5, SE=0.3 p=0.05) and dietary tracking (β=0.8, SE=0.3 p=0.02) were individually statistically associated with higher weight at 24 months. Additionally, the joint model indicated the presence effect modification (β=-0.3, SE=0.2 p=0.01). However, these associations were not significant at 12 months. Although the individual models that tested the associations of long gaps on weight were not statistically significant, the results of the joint model suggested statistically significant effect measure modification. Finally, increases in the number of extra long gaps in PA self-monitoring (β=3.7, SE=1.3 p=0.01) and in dietary self-monitoring (β=2.9, SE=1.4 p=0.04) were associated with higher weight at 12 months. The correlation between extra long gaps in dietary and PA self-monitoring resulted in the large standard errors of the dietary tracking gaps in the joint model. These findings were approximately the same at 24 months.

Discussion and Limitations

Consistent with previous work that links adherence to behavioral outcomes [86-88], the associations of total adherence with both MVPA and weight outcomes were highly significant at both 12 and 24 months in this sample. However, to improve intervention outcomes, it is critical to seek out indicators that provide information earlier about when to intervene. In order to offer timely support for individuals who show signs of disengagement early during behavioral weight loss interventions, this analysis examined different self-monitoring characteristics beyond broad adherence measures. Results supported the hypothesis that later onset and greater frequency of gaps in physical activity self-monitoring during intervention will be associated with lower reported physical activity levels measured at 12-month and 24-month follow-up. Total number of PA self-monitoring gaps and increases in the average length of the gap were associated with less physical activity at 12 and 24 months. Additionally, late onset of physical activity tracking was associated with decreased MVPA at 12 and 24 months. Finally, as the first gap in self-monitoring occurred later in time, reported MVPA also increased. These findings suggest that encouraging and sustaining initial individual engagement in PA self-monitoring as a tool for short- and long-term MVPA participation is pivotal. This work complements previous work [87, 92, 93] examining effects of PA self-monitoring on participation by using more objective self-monitoring measures as well as extending follow-up time. Further, these results suggest that observing gaps in self-monitoring via electronic data collection during active weight loss interventions may be a useful tool to identify participants who may be susceptible to behavioral relapse or disengagement.

Increases in short, medium and long length gaps were not statistically associated with MVPA participation. However, this may be indicative of low power to detect a significant effect due to the low frequency of gaps. Table 4 shows that during the first year of intervention participants had on average 2.6 (±2.4) small gaps and less than one each of medium, large and extra-large gaps during the first year of intervention. Nevertheless, a dose-response relationship at both 12 and 24 months is indicated by the effect sizes. Increases in short gaps are associated with the smallest decrease in MVPA while extra long gaps appear to have the largest decrease in MVPA. Future investigation using larger samples with a variety of self-monitoring gaps sizes is needed to clarify this relationship.

The strong statistical association between extra long-gaps in behavior tracking and MVPA suggests that individuals who have gone more than 12 weeks, or approximately 3 months, without tracking during a behavioral weight loss intervention could likely benefit from intervention augmentation or modification. A number of behavioral interventions are often one year in duration. Additionally, strategies that seek to reengage individuals showing little self-monitoring activity within a 3-month time frame may be one way to improve and optimize interventions for successful physical activity outcomes. Strategies to consider include personalized barrier assessments [94], reframing of regulatory focus

[95], and introducing groups or partners to promote accountability [96].

Results also supported the hypothesis that later onset and greater frequency of gaps in physical activity self-monitoring during intervention will be associated with higher weight at 12-month and 24-month follow-up. Late onset of PA self-monitoring, measured as early as the second week of the weight loss intervention, was associated with approximately 3.0 kg difference in weight at both 12 and 24 months. Further, among individuals who had self-monitoring gaps, weight was inversely associated with the timing of the initial gap in PA tracking. Additionally, increases in total number of PA self-monitoring gaps were associated with increases in weight at both 12 and 24 months. Models examining dietary tracking characteristics resulted in similar findings. However, late onset of dietary tracking was not statistically associated with weight at 12 or 24 months. This may be due to the high number of participants who began tracking diet within the second week of intervention (n=269).

Results of the joint models incorporating the association of both diet and PA tracking behaviors with weight varied greatly. Due to the correlation between the two tracking behaviors the models for late onset of tracking, average length of gap, and extra long gaps resulted in effects that had very large standard errors. Therefore, the independent models give more information about the associations between self-monitoring characteristics and weight outcomes. Effect measure modification appeared to be present in the joint models that examined week of first gap and total number of gaps and 24-month weight. Figures 7 and 8 depict these relationships using composite variables of PA and dietary tracking. For the appearance of the first tracking gap, the effect modification appears to be driven largely by the group of individuals who did not have a gap in self-monitoring in either PA or diet until later in the study. Figure 8 shows the differences in 24 month weight when total gaps in PA tracking and dietary tracking vary.

When considering gap length, results varied widely. Increased frequency of short length gaps was associated with weight at 24 months but not at 12 months in the independent models. However, in the joint model, increased frequency of short gaps in both PA and dietary self-monitoring were associated statistically with weight. Further, effect measure modification appears to be present. Figure 9 depicts this association using composite variables. The effects of increased short gaps would suggest that when monitoring behavior tracking, increased frequency of gaps lasting 1-3 weeks in PA or dietary tracking should raise concerns and indicate a need for intervention adjustment.

Increased frequency of long gaps in tracking was not independently associated with weight at 12 or 24 months. However, the joint models appeared to support effect modification. Figure 10 indicates that the effect of higher frequency of long gaps in PA self-monitoring was modified by the effect of increased long gaps in dietary self-monitoring, such that less weight is gained over time when long gaps in both tracking behaviors are present. This antagonistic interaction would suggest that those who have gaps in monitoring both diet and PA are not at any additional increased risk of high weight compared to those who are only monitoring one behavior or the other. However, considering the low number of medium, long and extra long gaps in this sample, these results should be interpreted cautiously.

Finally, an increase in dietary and PA self-monitoring gaps lasting longer than 12 weeks was independently associated with weight at both 12 and 24 months. However, in the joint model, the standard error for the dietary gaps was very large, again likely due to correlation. The independent models further support, observing diet and PA tracking remain important factors for intervention monitoring.

This paper offers insight into opportunities for identifying individuals at risk for behavioral disengagement using self-monitoring behaviors. These findings expand on previous work examining overall self-monitoring of physical activity adherence [87] by utilizing specifically defined self-monitoring characteristics. Further, the use of longer follow-up time offers the potential to evaluate how early signs of behavioral lapse may affect long-term behavioral and weight maintenance outcomes. Finally, by exploring the association of self-monitoring gaps on MVPA achievement and weight out to 24-months this analysis highlights specific and measurable criteria for intervention development. Using this information, no tracking within the second week of intervention, discontinuing self-monitoring early, or increased gaps in tracking should indicate behavioral disengagement and low adherence. Future investigations should examine quality of self-monitoring as well as more specific timing of gaps in tracking to provide earlier and more precise measures of self-monitoring adherence.

There are several limitations to this exploration not previously mentioned. This analysis relies on several assumptions regarding confounding. Although several demographic variables were examined and adjusted for in the models, it is likely that not all possible confounders were measured. Although this sample has a larger proportion of men (35%) than typical weight loss samples, this was still a fairly homogenous sample. Most individuals were white (86.4%), college educated (63.7%), and married or partnered (67.9%) [12]. These characteristics suggest that external validity is an issue and similar investigations using more diverse populations should be conducted. It should be noted that participants in the tracking study had additional weight loss support, including frequent group meetings, beyond self-monitoring. Therefore these findings are limited to a supportive weight loss intervention setting and cannot be extrapolated to the larger population using dietary and PA self-monitoring for self-guided weight loss.

Measurement error from self-reported MVPA limits this study further. Because the PAQ assesses individuals MVPA participation via self-report, individuals may over estimate MVPA. Differential over reporting of MVPA could potentially bias the results away from the null. However, it is plausible that this over estimation would occur in both groups of participants regardless of self-monitoring status due to social desirability of being in a weight loss intervention. Future work should use accelerometers for more objective MVPA measurement.

Defining a gap as a weeklong period in which the behavior of interest is not tracked is a broad measurement and may not adequately capture tracking adherence. Participants who did not track MVPA because they did not participate in MVPA and those who did not turn in a log regardless of MVPA participation were both counted as having a gap in tracking. Further, if participants were self-monitoring dietary and MVPA behaviors using other mobile applications, devices, or websites, their tracking would not have been captured for this analysis. Therefore, this analysis does not contribute to understanding the basic nature of tracking behaviors or how to improve tracking adherence. Additionally, because diet requires substantially more frequent logging than PA to capture the full behavior, this definition limits the conclusions that can be made about dietary tracking and how often or how detailed logs should be for successful outcomes. Nevertheless the insight provided by this analysis captures a self-monitoring for a fairly large sample over a substantial period of time.

Finally, although this paper addresses MVPA maintenance in a sample of individuals actively trying to lose weight, there is little that can be said about specific strategies that may be effective in ensuring high rates of 250 weekly minutes of MVPA achievement and continuation. Little is known about the mechanisms of behavioral maintenance and habit formation and how to intervene for improved behavioral and health outcomes. PA tracking may be a sufficient indicator of MVPA at 24 months simply because it indicates MVPA participation at 12 months. Going forward, it will be important to test intervention augmentation strategies so that once behavioral disengagement is detected, individuals are offered effective treatment strategies to enhance behavioral maintenance and weight loss success.

Conclusion

This study defined different characteristics of physical activity and dietary self-monitoring and examined their associations with MVPA achievement and weight change during a behavioral weight loss intervention. Late onset of PA tracking, and increases in total number of gaps in were associated with lower physical activity and higher weight at both 12 and 24 month time points. Moving forward, monitoring PA and dietary tracking logs should be considered to identify individuals who show signs of behavioral disengagement early to improve behavioral and weight maintenance.

Tables and Figures

Table 4: Weight change, physical activity, and self-monitoring characteristics of participants

Characteristics	Sample Mean (SD)
Baseline Weight, kg	95.5 (15.1)
12-Month Weight, kg	87.3 (15.2)
24-Month Weight, kg	90.3 (15.9)
Baseline MVPA kcal/wk, Measured by PAQ	1309.9 (1250.9)
12-Month MVPA kcal/wk, Measured by PAQ	2116.9 (1827.7)
24-Month MVPA, kcal/wk Measured by PAQ	2132.3 (1796.0)
Tracking Behaviors, Physical Activity	
Adherence (total number of days tracked)	101.5 (85.0)
First week of self-monitoring	1.6 (1.9)
Week of first gap	8.4 (11.3)
Average length of gap, weeks	11.6 (15.4)
Total number of gaps	3.7 (2.6)
Number of short (1-3 weeks) gaps	2.6 (2.4)
Number of medium (4-7 weeks) gaps	0.4 (0.7)
Number of long (8-11 weeks) gaps	0.1 (0.4)
Number of extra-long (12+ weeks) gaps	0.6 (0.5)
Tracking Behaviors, Diet	
Adherence (total number of days tracked)	179.3 (103.5)
First week of self-monitoring	1.2 (1.1)
Week of first gap	13.1 (14.1)
Average length of gap, weeks	11.0 (15.1)
Total number of gaps	2.7 (2.2)
Number of short (1-4 weeks) gaps	1.9 (2.0)
Number of medium (5-8 weeks) gaps	0.3 (0.6)
Number of long (9-12 weeks) gaps	0.1 (0.3)
Number of extra-long (>12 weeks) gaps	0.5 (0.5)

Table 5: Association of PA tracking behaviors and reported MVPA (kcal/wk) at 12 and 24 months

	12-month MVPA		24-month MVPA	
	β (SE)	*p*	**β**(SE)	*p*
Total days tracked	4.6 (0.8)	<0.01	4.9 (0.9)	<0.01
Late onset of PA tracking	-345.1 (137.2)	0.02	-323.7 (153.6)	0.04
Week of first gap*	26.1 (7.1)	<0.01	25.0 (7.8)	<0.01
Total number of gaps**	-252.8 (104.5)	0.02	-255.4 (123.2)	0.04
Average length of gap***	-118.8 (54.8)	0.03	-153.5 (56.8)	0.01
Short gaps (1-4 weeks)	-40.0 (26.5)	0.13	-35.3 (29.6)	0.23
Medium gaps (5-8 weeks)	-77.6 (116.1)	0.50	-84.1 (152.9)	0.06
Long gaps (9-12 weeks)	-252.9 (183.9)	0.17	-307.4 (185.5)	0.10
Extra long gaps (>12 weeks)	-472.8 (376.1)	<0.01	-544.3 (124.5)	<0.01

All adjusted models include demographic covariates gender, age, race, marital status, education level and study arm assignment
**Only includes participants with ≥1 gap in tracking during the active weight loss period*
***Scaled to IQR; total number of gaps per 4 week increment*
****Scaled to IQR; average length of gap per 11.8 week increment*

Table 6: Association of dietary tracking behaviors and reported MVPA (kcal/wk) at 12 and 24 months

	12-month MVPA		24-month MVPA	
	β(SE)	*p*	**β**(SE)	*p*
Total days tracked	1.8 (0.7)	<0.01	1.9 (0.8)	0.01
Late onset of PA tracking	-140.3 (166.9)	0.40	-113.7 (179.4)	0.53
Week of first gap*	4.6 (5.8)	0.43	6.9 (6.6)	0.37
Total number of gaps**	-124.2 (84.4)	0.14	-158.7 (93.4)	0.08
Average length of gap***	-148.5 (61.7)	0.02	-183.5 (64.7)	<0.01
Short gaps (1-4 weeks)	-17.5 (158.8)	0.91	-39.2 (30.6)	0.20
Medium gaps (5-8 weeks)	-17.4 (116.1)	0.50	-27.6 (211.5)	0.90
Long gaps (9-12 weeks)	-188.3 (177.9)	0.29	-273.6 (180.4)	0.13
Extra long gaps (>12 weeks)	-190.2 (128.3)	0.14	-239.1 (137.9)	0.08

All adjusted models include demographic covariates gender, age, race, marital status, education level and study arm assignment
**Only includes participants with ≥1 gap in tracking during the active weight loss period*
***Scaled to IQR; total number of gaps per 4 week increment*
****Scaled to IQR; average length of gap per 11.8 week increment*

Table 7: Correlation of physical activity and dietary tracking measures

Tracking Variable	Correlation of physical activity and dietary tracking (*r*)
Average length of gap	0.91
Late onset of tracking	0.64
Week of first gap	0.66
Total number of gaps	0.59
Short gaps (1-4 weeks)	0.51
Medium gaps (5-8 weeks)	0.55
Long gaps (9-12 weeks)	0.30
Extra long gaps (>12 weeks)	0.76

Table 8: Association of PA and dietary tracking behaviors and weight (kg) at 12 months

	PA Tracking Model		Dietary Tracking Model		Joint Model					
					PA tracking		Dietary tracking		Interaction	
	β(SE)	*p*	**β**(SE)	*p*	**β**(SE)	*p*	**β**(SE)	*p*	**β**(SE)	*p*
Total days tracked	-0.04 (4.1)	<0.01	-0.03 (0.01)	<0.01	-0.03 (0.01)	0.04	-0.01 (0.01)	0.41	--	--
Late onset of tracking	3.0 (1.3)	0.02	2.3 (1.6)	0.15	2.9 (1.6)	0.07	0.01 (2.0)	0.99	--	--
Week of first gap*	-0.2 (0.1)	<0.01	-0.1 (0.1)	0.05	-0.5 (0.2)	0.01	-0.1 (0.1)	0.32	0.01 (0.01)	0.05
Total number of gaps**	2.6 (1.0)	<0.01	2.2 (0.9)	0.02	1.8 (1.1)	0.12	1.3 (1.1)	0.23	--	--
Average length of gap***	0.7 (0.5)	0.14	0.8 (0.5)	0.12	-0.03 (1.1)	0.97	0.9 (1.3)	0.49	--	--
Short gaps (1-4 weeks)	0.4 (0.3)	0.17	0.6 (0.3)	0.09	0.8 (0.4)	0.05	1.4 (0.6)	0.01	-0.3 (0.1)	0.04
Medium gaps (5-8 weeks)	2.6 (1.0)	0.01	0.9 (1.1)	0.43	3.1(1.1)	<0.01	-1.1 (1.3)	0.39	--	--
Long gaps (9-12 weeks)	0.8 (1.8)	0.66	2.4(2.0)	0.25	2.9 (2.2)	0.20	5.4 (2.1)	0.01	-9.8 (4.2)	0.02
Extra long gaps (>12 weeks)	3.7 (1.3)	0.01	2.9 (1.4)	0.04	3.7 (1.8)	0.04	0.03 (1.97)	0.99	--	--

All adjusted models include demographic covariates gender, age, race, marital status, education level and study arm assignment
**Only includes participants with ≥1 gap in tracking during the active weight loss period*
***Scaled to IQR; total number of gaps per 4 week increment*
****Scaled to IQR; average length of gap per 11.8 week increment*

Table 9: Association of PA and dietary tracking behaviors and weight (kg) at 24 months

	PA Tracking Model		Dietary Tracking Model		Joint Model					
					PA tracking		Dietary tracking		Interaction	
	β(SE)	*p*	**β**(SE)	*p*	**β**(SE)	*p*	**β**(SE)	*p*	**β**(SE)	*p*
Total days tracked	-0.04 (0.01)	<0.01	-0.03 (0.01)	<0.01	-0.03 (0.01)	0.04	-0.01 (0.01)	0.21	--	--
Late onset of tracking	3.0 (1.4)	0.03	2.6 (1.7)	0.14	2.8 (1.7)	0.11	0.4 (2.2)	0.86	--	--
Week of first gap*	-0.2 (0.1)	<0.01	-0.1 (0.1)	0.05	-0.5 (0.2)	0.01	-0.1 (0.1)	0.22	0.01 (0.01)	0.05
Total number of gaps**	3.2 (1.0)	<0.01	2.9 (0.9)	<0.01	2.6 (1.2)	0.03	3.2 (1.2)	<0.01	-2.8 (1.5)	0.05
Average length of gap***	0.7 (0.5)	0.13	0.9 (1.1)	0.42	0.4 (1.2)	0.75	0.4 (1.4)	0.77	--	--
Short gaps (1-4 weeks)	0.5 (0.3)	0.05	0.8 (0.3)	0.02	1.0 (0.4)	0.02	1.9 (0.6)	<0.01	-0.3 (0.2)	0.01
Medium gaps (5-8 weeks)	2.8 (1.0)	0.01	1.0 (1.2)	0.40	3.4 (1.2)	<0.01	-1.3 (1.4)	0.37	--	--
Long gaps (9-12 weeks)	1.5 (1.9)	0.41	2.9 (2.0)	0.16	3.5 (2.3)	0.13	5.8 (2.2)	0.01	-9.7 (4.3)	0.02
Extra long gaps (>12 weeks)	3.8 (1.4)	0.01	3.0 (1.5)	0.04	3.9 (1.9)	0.04	-0.1 (2.1)	0.97	--	--

All adjusted models include demographic covariates gender, age, race, marital status, education level and study arm assignment
**Only includes participants with ≥1 gap in tracking during the active weight loss period*
***Scaled to IQR; total number of gaps per 4 week increment*
****Scaled to IQR; average length of gap per 11.8 week increment*

Figure 6a: Participant PA self-monitoring during active weight loss intervention. Participants were sorted by week of first gap in tracking followed by number of weeks tracked. The weeks when PA was tracked were coded in red; the weeks when PA was not tracked were coded in grey.

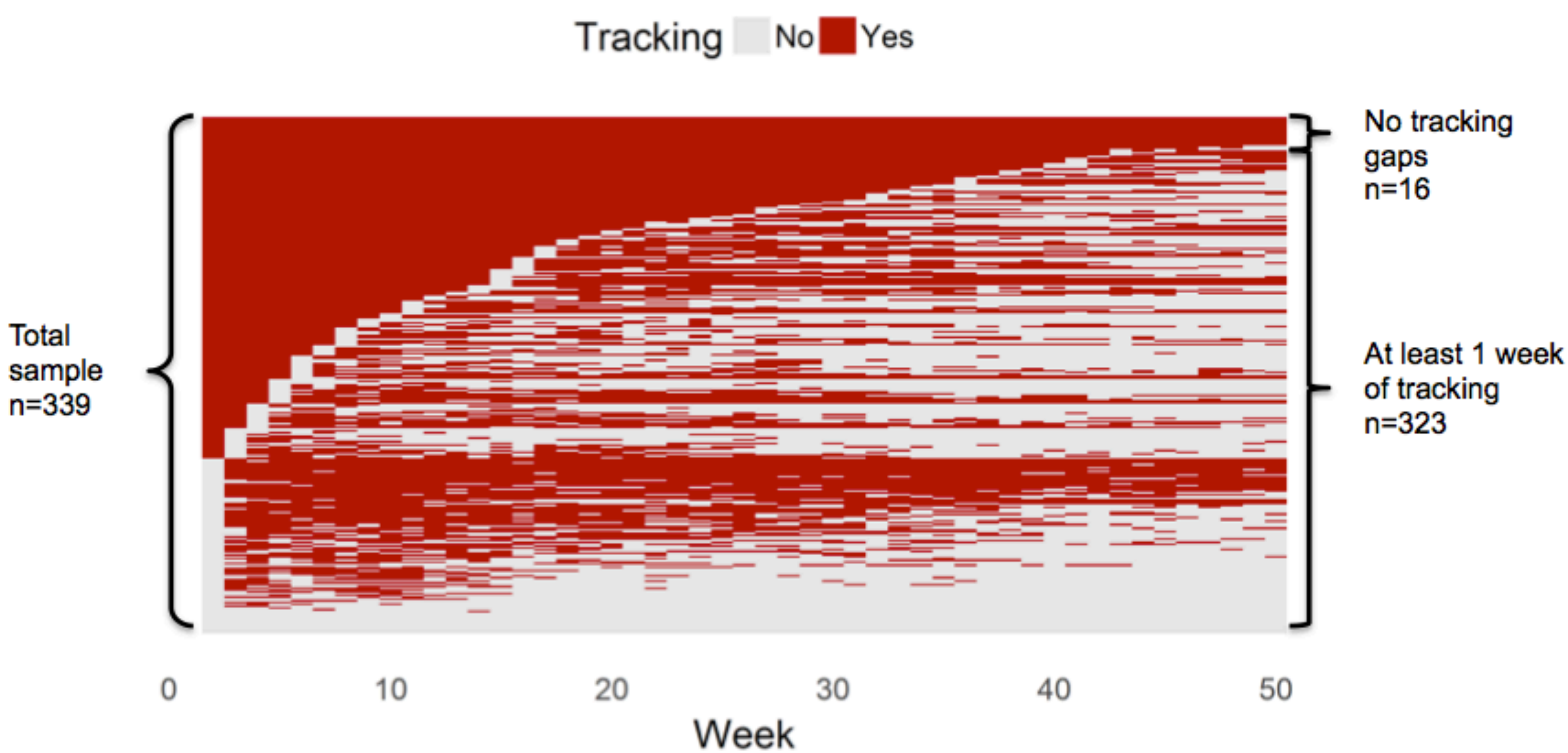


Figure 6b: Participant dietary self-monitoring during active weight loss intervention. Participants were sorted by week of first gap in tracking followed by number of weeks diet was tracked. The weeks when diet was tracked were coded in green; the weeks when diet was not tracked were coded in grey.

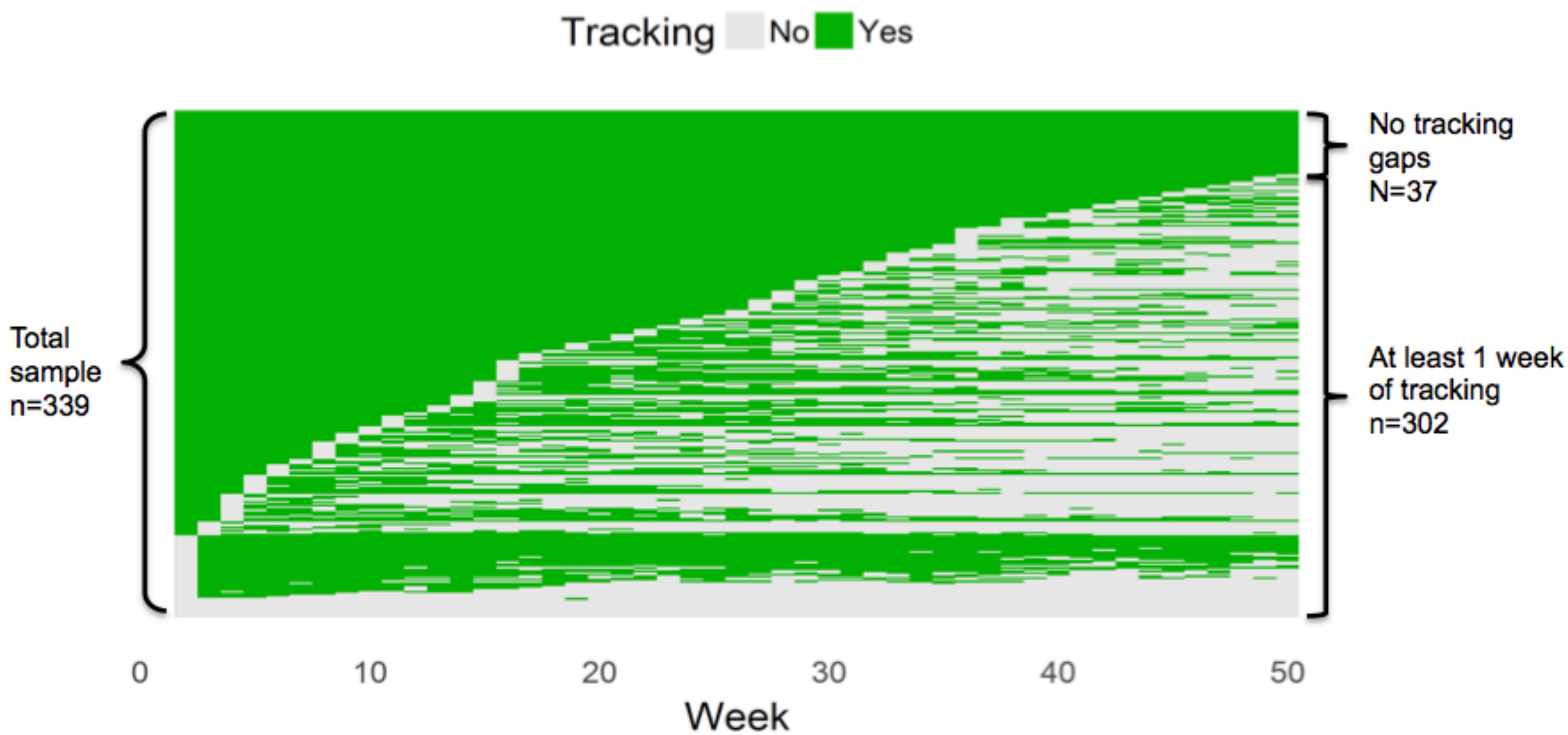
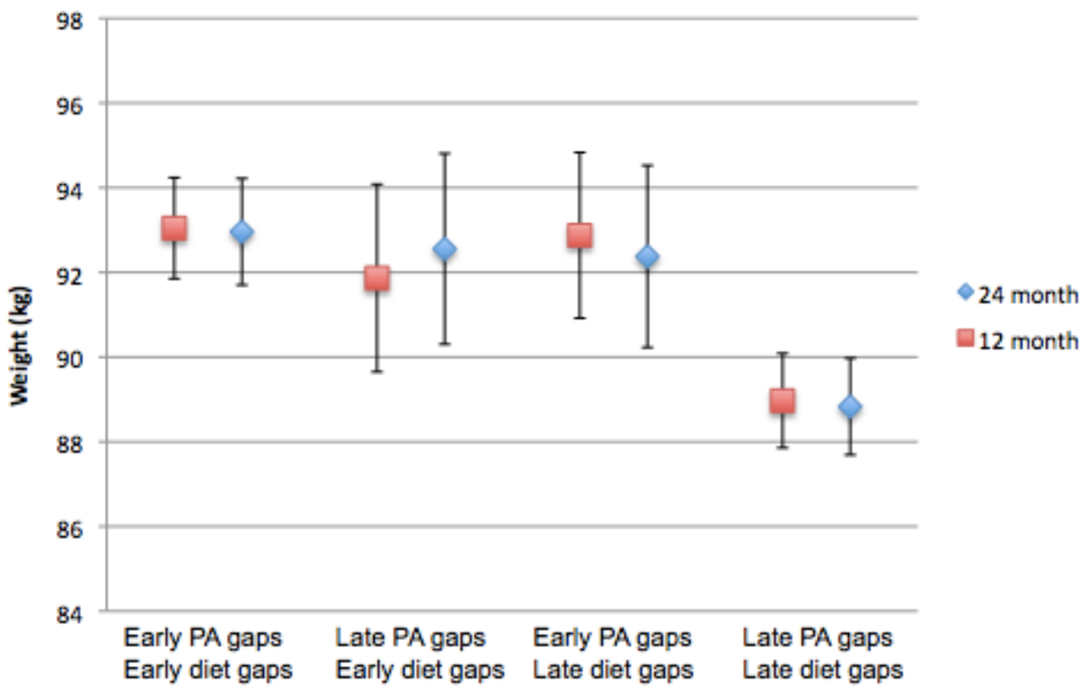
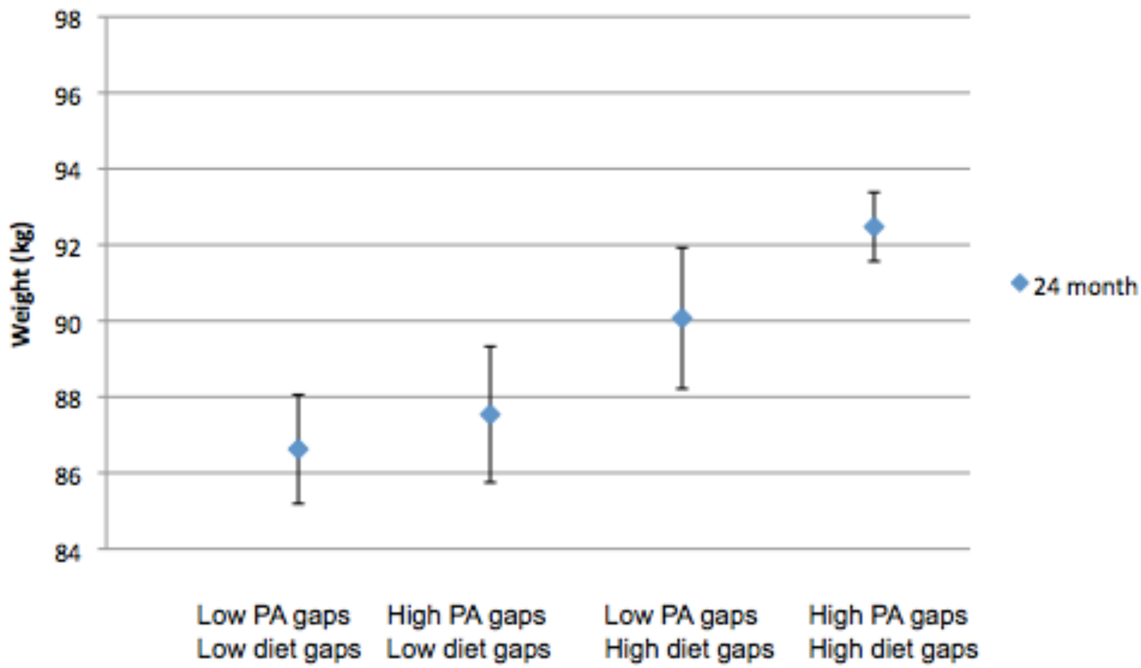


Figure 7: First gap in PA and dietary self-monitoring estimated mean weight at 12 and 24 months



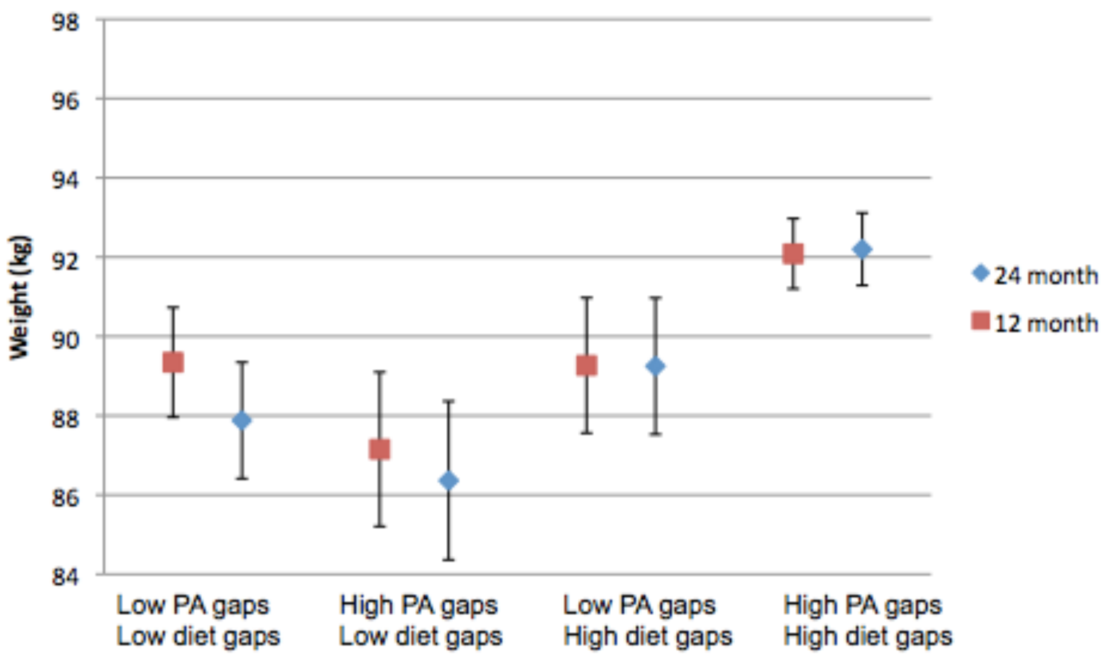
**PA and dietary self-monitoring variables were divided using the median number of weeks for the cut points. Composite variables were then formed. Early PA gaps: earlier than week 3; Early diet gaps: earlier than week 10*

Figure 8: Total gaps in PA and dietary self-monitoring estimated mean weight at 24 months



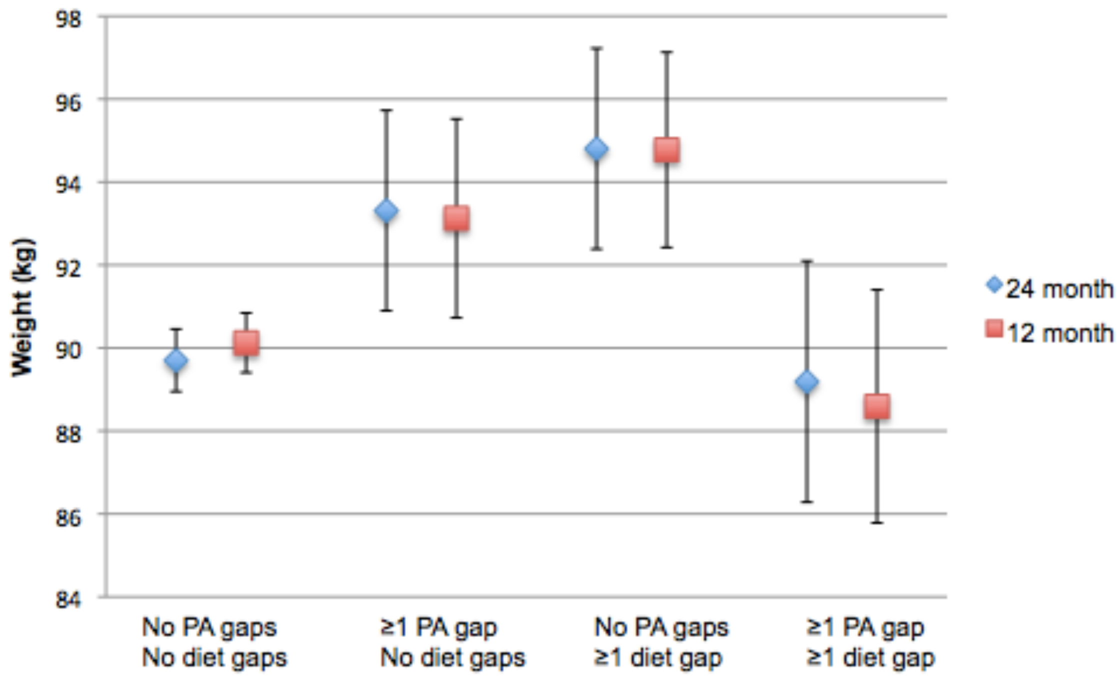
**PA and dietary self-monitoring variables were divided based on the IQR used for standardization in the models. Composite variables were then formed. Low PA gaps:<11.2 gaps ; Low dietary gaps: <11.4 gaps*

Figure 9: Short gaps in PA and dietary self-monitoring estimated mean weight at 12 and 24 months



**PA and dietary self-monitoring variables were divided using the median number of short gaps for the cut points. Composite variables were then formed. Low PA gaps: < 2 gaps; Low dietary gaps: < 3 gaps*

Figure 10: Long gaps in PA and dietary self-monitoring estimated mean weight at 12 and 24 months



**PA and dietary self-monitoring variables were divided using the median number of gaps for the cut points. Composite variables were then formed.*

CHAPTER 5

MANUSCRIPT #3: Differential effects of a light physical activity intervention delivered in the workplace

Overview

Low rates of MVPA achievement by American adults coexist with increases in sedentary time at the population level. Because adults spend an average of 7.4 hours per day in the workplace and increased sedentary time spent at work is correlated with increases in BMI, the workplace has been identified as a potential intervention delivery domain. In order to identify the potential benefits of a light physical activity (LPA) intervention for health and behavioral achievement in adults with overweight and obesity, this study examined data from a recent worksite intervention. This work offers insight into the efficacy of LPA recommendations and interventions in promoting LPA achievement and adherence for adults with overweight and obesity who may find it challenging to achieve and maintain recommended levels of MVPA. This secondary analysis utilized data from the Stand & Move at Work group-randomized worksite LPA intervention trial conducted in 24 worksites throughout the Minneapolis-St. Paul, MN and Phoenix, AZ metropolitan areas. Recruitment began in 2016 and 1-year follow-up measures are currently underway. LPA was measured at baseline and at 3 months by activPAL accelerometers worn continuously for 7 days during measurement periods. Height and weight was measured at baseline by trained staff. Linear mixed models examined the association of BMI category with baseline work time LPA participation, all day LPA participation, and change in work time LPA participation from baseline to 3 months. At baseline, participants in the normal weight BMI category participated in 2.81 more minutes per 8-hour day (SE=1.46 minutes; p=0.06) of LPA during work hours than those in the obese BMI category. Those in the overweight BMI category participated in LPA 2.39 minutes (SE=1.41 minutes; p=0.09) longer per 8 hours than those in the obese category. Total daily LPA participation varied by BMI category so that those in the normal weight category participated in PA 12.97 minutes (SE=2.83; p<0.01) longer per 16-hour day than those in the obese BMI category, while those in the overweight category participated in PA 7.71 (SE=2.73; p<0.01) minutes longer. At three months, participants with BMI in normal weight (3.22 minutes; SE=1.30; p=0.01) or overweight (2.84 minutes; SE=1.25; p=0.02) categories participated in work time LPA longer than participants with BMI in the obese category. These findings suggest that this worksite LPA intervention may be similarly effective for those with normal and overweight BMI. Future work into worksite health interventions including those that target health screenings, diet and/or physical activity, weight management, and stress reduction should seek to examine potential differential effects by weight status.

Introduction

The Physical Activity Guidelines for Americans for overall general health promotion recommend that adults achieve a minimum combination of 150 minutes of moderate PA or 75 minutes of vigorous PA weekly [97]. Further, research examining the optimal level of physical activity (PA) for sustained weight loss suggests a minimum of 250-300 minutes of moderate to vigorous physical activity (MVPA) per week [98].

Unfortunately, most American adults do not come close to achieving this high level of MVPA. According to CDC investigations using data from the Behavioral Risk Factor Surveillance System (BRFSS), only 31% of adults self-report achieving 300 minutes of moderate PA [41]. Further, investigations using accelerometer data to assess adherence to the Physical Activity Guidelines for Americans found that between 8.2% and 44.6% of adults achieved recommended levels of PA [97]. Increases in BMI have been correlated with decreases in PA participation, suggesting that individuals with higher BMI are participating in even fewer minutes of PA [99, 100]. Additionally, analyses using data from over 50,000 women enrolled in the Nurses' Health Study cohort found that sedentary behaviors including TV viewing and sitting at work were associated with a 23% and 5%, respectively, increased risk of obesity over a 6-year follow-up [101]. As the prevalence of overweight and obesity in adults remains high at 68.5% in the U.S. [1], and because high BMI is associated with many health concerns that PA has been shown to attenuate [3, 6-11], identifying strategies to increase PA and decrease sedentary behavior in adults with high BMI is imperative for public health improvement. Therefore, interventions that promote PA levels that are more achievable and maintainable for a large proportion of adults are of interest.

Current low rates of MVPA coexist with increases in sedentary time at the population level, in part due to changing transportation, home, and work environments in the US and around the world. Currently, Americans across all ages spend an average of 7-8 hours per day engaged in sedentary activities [42]. Because American adults spend an average of 7.4 hours per day in the workplace [102] and increased sedentary time spent at work is correlated with increases in BMI [103], the workplace has been identified as a potential intervention delivery domain [104, 105]. Worksite interventions have focused on increasing PA through counseling, group and self-instruction, environmental changes and prompts, as well as goal setting and incentives [52]. PA interventions implemented in the worksite have targeted reducing risks for obesity, CVD, and diabetes outcomes as well as improving fitness and increasing PA [52]. These interventions have had substantial heterogeneity in intervention design and delivery as well as target outcome measurement. Nevertheless, PA interventions that produce achievable and sustainable results that can be delivered in the workplace have the potential to provide large-scale public health benefits.

One potential strategy is to improve light intensity physical (LPA) activity in the workplace. Beyond the benefit of being able to perform LPA, non-exercise activity, with minimal productivity interruption, it may be easier for individuals with higher BMI to adopt and continue. However, differential effects of worksite PA interventions by obesity status have yet to be explored. Exploring PA participation by obesity status is integral to ensuring that interventions are successfully impacting individuals who have elevated risk for negative health outcomes and potentially stand to benefit the most from the intervention. Further, assessing behavioral outcomes of an LPA intervention by obesity status offers insight into the utility of lower intensity recommendations and interventions for individuals who may struggle to achieve sufficient PA.

In order to identify the potential benefits of a LPA intervention for health and behavioral achievement in adults with overweight and obesity, this study examined data from a recent worksite intervention. Data from the Stand & Move at Work trial, a worksite intervention designed to increase light physical activity and standing during the work day, were used to examine the effect of a worksite intervention on LPA participation modified by baseline BMI (Figure 6). This study had the following hypotheses*: (1) baseline BMI will be inversely associated with physical activity measured at baseline, so that employees with higher BMI will have participated in light intensity physical activity less frequently than employees with lower BMI prior to intervention; (2) baseline BMI will no longer be inversely associated with light intensity physical activity participation at 3 months during a worksite intervention aimed at increasing light intensity physical activity participation to 30 minutes during the workday*. By addressing these hypotheses, this work offers insight into the efficacy of LPA recommendations and interventions in promoting LPA achievement and adherence for adults with overweight and obesity who may find it challenging to achieve and maintain recommended levels of MVPA. Further, this analysis offers feedback and information about uptake and LPA participation by BMI category for future community intervention design and implementation.

Methods

Study Design:

This secondary analysis utilized data from a group-randomized worksite LPA intervention trial. The Stand & Move at Work trial sought to compare a multi-level LPA worksite environment intervention to a condition utilizing the same intervention components augmented with a sit-stand workstation. The main behavioral outcomes of the original trial were LPA during the workday and reduced sitting time. The primary health outcomes included cardiometabolic risk factors: blood pressure, cholesterol, triglycerides, fasting blood glucose and insulin. This trial was comprised of a 12-month active intervention with a 12-month measurement-only follow-up period and was conducted in 24 worksites throughout the Minneapolis-St. Paul, MN and Phoenix, AZ metropolitan areas [13].

Each geographic location enrolled and randomized 12 worksites to either the MOVE+ worksite intervention condition or to the STAND+ worksite intervention condition (i.e., the MOVE+ intervention supplemented with sit-stand workstations). The worksites were enrolled and randomized, in waves of four (two worksites in each geographic area) staggered every two months, beginning in January 2016. Enrollment concluded in November of 2016. Following a baseline visit, stratified block randomization was employed to ensure that an equal number of worksites in each region were assigned to intervention and comparison conditions [13]. This study was approved by both the University of Minnesota and Arizona State University Internal Review Boards.

Intervention:

The MOVE+ intervention was a worksite intervention intended to encourage employees to achieve a minimum of 30 minutes of LPA during the workday [13]. This intervention used a social-ecological approach to program delivery. Interventions targeted at the individual, social, environmental, and organizational levels within the worksite were utilized to encourage increased LPA and reduced sitting. Individual approaches included self-assessment and goal setting tools, newsletters sent out regularly to employee email accounts, and training to overcome lapses and prevent relapse. Social approaches included the use of office "Champions" and leaders to encourage engagement as well as wellness events in the office. The use of signage and reorganizing office environments encouraged LPA at the environmental level. Reorganization entailed removing personal waste bins and replacing them with community waste bins, and designated walking routes within the workplace environment. At the organizational level, senior managers and leaders were recruited to support intervention activities, and to enact policy changes to encourage LPA during office hours. These intervention efforts were implemented for 12 months following enrollment and randomization.

Worksites randomized to the STAND+ intervention received the MOVE+ worksite intervention as well as personal sit-stand workstations installed for participating employees. These workstations manually transition between sitting and standing positions so that employees can easily choose their position preference. Upon installment, participants were instructed to stand for an hour per day in 15-20 minute episodes. Individuals could then gradually increase standing each day by 15-20 minutes. The goal of the Move+ intervention was to encourage employees to achieve a 50% balance between standing and seating time while at their desks. Further details of the Stand & Move at Work trial can be found elsewhere [13].

Study Population:

Worksite Eligibility: Worksites in both Minnesota and Arizona were small to moderate in size, employing 20-60 individuals, 80% of whom were employed full-time.

All worksites had desk-based occupations, were not offering other wellness programs, and were willing to have sit-stand workstations installed in the office [13]. The 24 worksites in the study were drawn from government, academic, and healthcare/industry domains.

Individual Eligibility: While worksites were the unit of randomization and intervention, employees were the unit of measurement and thus, employees at each recruited site were encouraged to enroll individually in study activities as participants. Individuals enrolled at the workplace were required to be employed full-time in a sedentary occupation with a traditional seated desk and willing to be randomized to receive a sit-stand workstation. Additionally, in order to participate, employees were at least 18 years of age or older, in good health and physically able to perform LPA [13]. Exclusion criteria included pre-existing health conditions and pregnancy at time of recruitment. Eligibility was verified during worksite recruitment and baseline visits. Study staff recruited a total of 641 employees across the 24 participating worksites.

During the baseline worksite visit, study staff verified eligibility and consented participants. Following consent, trained staff took blood samples, cardiometabolic (i.e., blood pressure, fasting blood glucose) and anthropometric (i.e., height, weight, body fat percentage) measurements, and reviewed instructions for self-reported survey completion. Self-report surveys were conducted online through Qualtrics Survey Software (Qualtrics, Provo, Utah). Finally, all participants were given an activPAL accelerometer along with directions for wear.

Exposure Assessment:

BMI

At baseline, trained staff took height and weight measurements. Participants were measured while wearing lightweight shorts and t-shirts, without shoes. BMI was calculated as a continuous variable. Based on this calculation, weight categories were defined based on the World Health Organization's international BMI definitions [106]: normal weight (18.5–24.9 kg/m^2), overweight (25–29.9 kg/m^2), and obese (≥30 kg/m^2).

Outcome Assessment:

Light Intensity Physical Activity

Total LPA and work time LPA assessed at baseline were examined as the main outcomes for the first hypothesis. Further, LPA was assessed at baseline and 3-month follow-up periods as the main outcome for the second hypothesis. Both total LPA and work time LPA were measured using the same objective data capture device. All participants were instructed to wear activPAL accelerometers (PAL Technologies, Glasgow, Scotland) continuously for 7 days at baseline and again at 3 months. The devices were water-proofed and fixed to the middle of the left thigh of the subjects during measurement visits, along with instructions for wear and completion of daily logs. These accelerometers weigh 20g each and adhere directly to the skin (PAL Technologies Ltd., Glasgow, Scotland). These accelerometers are capable of capturing posture (i.e. sitting vs. standing) and more precise measures of behaviors with lower energy expenditure than can be detected using the ActiGraph GTX3[107]. Further, in comparison to direct observation, activPAL data has shown strong correlation (r= 0.94) with standing and light activity time [108].

Total LPA included all measured LPA defined by PAL technologies, over the days the activPAL was worn. Total LPA measures were then standardized to a 16-hour day. Date and time-stamped PA measurements were used to define time spent in work time LPA only, measured on work days and standardized to the 8-hour workday, were averaged over the five-day work period to measure continuous mins/day of LPA. LPA was identified using manufacturer defined cut points of movement measured in collected epochs.

Covariate Assessment:

Demographic variables including age, gender, race, marital status and level of education were self-reported at baseline using the Qualtrics online survey tool. Age at baseline was treated as a continuous variable. Gender (male vs. female), race (white non-Hispanic vs. non-white), marital status (married or partnered vs. other), and education level (less than a 4-year college degree vs. 4-year college degree or more) were defined as binary variables. Worksite, sector, and intervention arm variables were modeled as group level covariates.

Analysis

Sample descriptive characteristics at baseline and analyses were calculated in SAS version 9.4 (Cary, NC). In order to examine individual level characteristics for hypothesis 1 hierarchical modeling (PROC MIXED) was used to account for nesting of individuals in worksites. In the unadjusted model, the association of BMI category and continuous PA participation was examined. To measure working time LPA, the first model evaluated LPA during work hours on workdays. Work time LPA was standardized to an 8-hour working day using date and time output. A second model evaluated total daily LPA on all days the activPAL was worn. Total LPA was standardized to a 16-hour day to include leisure time PA before and after work. A random intercept for worksite was assigned to account for correlation due to clustering by worksite. Accounting for worksite level clustering was necessary due to the likelihood that employees within a worksite would have correlated PA values. By assigning a random intercept for worksite, this model estimated the average difference in PA based on BMI differences of employees within a worksite. Individual level demographic characteristics (age, race, gender, educational attainment, marital status) were included in the full model as fixed effects.

For hypothesis 2, hierarchical modeling was also utilized assigning random effects for individuals nested in worksites and time. In the unadjusted model, the outcome LPA during work hours on workdays was treated continuously for each individual. The random effects model accounts for correlation due to both cluster level worksite and individual level changes over time. A random intercept for worksite accounts for effects of the LPA intervention clustered by worksite. Further, the random effect for time accounts for changes in LPA over time for each individual from baseline to 3 months. Fixed effects for demographic variables were included in the adjusted model as well as a fixed effect for treatment assignment.

Results

This sample had a fairly even distribution of participants in BMI categories. The largest number of participants had BMI values in the obese category (n=223; 39%).

Approximately the same number of participants had BMI in the normal weight (n=173; 30%) and overweight (n=179; 31%) categories. Sample demographics are provided in Table 10. BMI categories were balanced across gender, race, educational attainment and marital status categories. Of note, statistical tests suggest a greater number of non-Hispanic white participants in the normal weight category than the overweight and obese BMI categories ($p=0.04$). Additionally, there was a higher proportion of participants with a 4-year college degree or greater in the normal weight category than the overweight category and obese categories; the obese category had the lowest proportion of individuals with a college degree ($p<0.01$). Sector was tested as a covariate and did not appear to impact effect size considerably. Therefore sector was not included in the current statistical models. Finally, intervention arm was adjusted for in all statistical models. However, because the study is still ongoing, covariate effects were not reported.

The intraclass correlation (ICC), which indicates the correlation of work time physical activity between individuals in each worksite, was estimated to be 0.157. Using the ICC a variance inflation factor (VIF) of 9.32 was calculated. This VIF supported the necessity to account for correlation by worksite in the models.

Baseline associations of work time LPA and BMI category are reported in Table 11. Crude models show no statistically significant difference in LPA participation across BMI category. In the adjusted model, participants in the normal weight BMI category participated in 3.05 more minutes per 8-hour day (SE=1.44 minutes; $p=0.04$) of LPA during work hours than those in the obese BMI category. Those in the overweight BMI category participated in LPA 2.39 minutes (SE=1.41 minutes; $p=0.09$) longer per 8 hours than those in the obese category. Age was statistically significantly associated with LPA participation during the workweek, so that an increase in 1 year of age of the participants was associated with an increase in work time LPA participation of 0.15 minutes per 8 hours (SE=0.06; p=0.01). Further, race was also associated with LPA, such that non-Hispanic white participants participated in LPA 5.31 fewer minutes (SE=1.46; p<0.01) than those with other racial backgrounds.

In contrast with work time LPA participation during working hours, total daily LPA participation varied more by BMI category (see Table 12). The crude and adjusted models had similar results. After adjustment, those in the normal weight category participated in PA 13.63 minutes (SE=2.80; p<0.01) longer per 16-hour day than those in the obese BMI category, while those in the overweight category participated in PA 7.77 (SE=2.74; p<0.01) minutes longer. Again, age was associated with total daily LPA, such that a 1-year increase in age was statistically associated with a 0.25-minute (SE=0.11; p=0.03) per 16-hour day increase in total daily LPA. All other covariates were not statistically significantly associated with LPA.

BMI associations with change in LPA from baseline to 3 months are reported in Table 13. The unadjusted model showed no statistical differences across BMI category for daily LPA participation. However, the final covariate adjusted model showed that participants with BMI in normal weight (3.38 minutes; SE=1.28; p=0.01) or overweight (2.82 minutes; SE=1.25; p=0.02) categories participated in work time LPA longer than participants with BMI in the obese category. Similar to the baseline model, a 1-year increase in age was associated with a 0.13-minute (SE=0.05; p=0.01) increase in LPA.

Finally, non-Hispanic white participants participated in 4.18 fewer minutes of LPA (SE=1.30; p<0.01) per 8-hour workday than participants of other races.

Discussion and Limitations

This analysis adds to the current understanding of participation in LPA for adults with overweight and obesity by evaluating LPA achievement and continuation, as moderated by overweight and obesity status. To our knowledge, the differential effects of worksite interventions to increase PA have not been previously examined while simultaneously considering BMI. The use of objective outcome measures for LPA is an additional strength. Results of statistical analyses examining obesity status and baseline physical activity somewhat support the first hypothesis, *that baseline BMI will be inversely associated with physical activity measured at baseline, so that employees with higher BMI will have participated in light intensity physical activity less frequently than employees with lower BMI prior to intervention*. Adjusted models in Tables 10 and 11 show a generally decreasing trend in PA as BMI category increases. Participants having normal range BMI had higher measured work time LPA participation than those with BMI in the obese range. Additionally, individuals with BMI in the overweight category also had higher work-time LPA participation than individuals in the obese category. This effect, though similar to the normal weight category, was not statistically significant at baseline. However, these findings suggest that, prior to intervention individuals in the obese category participate in work time LPA less frequently than those in the overweight and normal weight categories during the workday.

When total daily LPA was examined, the inverse association between BMI category and minutes of PA was more pronounced. The difference in total daily LPA participation between normal and obese BMI categories was larger than overweight and obese BMI categories (13.63 minutes and 7.77 minutes respectively). Further, estimated differences were statistically significant. These findings for daily LPA are congruent with previous work that has examined the association of PA on weight status[100] that has found that as BMI increases PA tends to decrease. Although Pate and others found in a representative sample of adults that MVPA was inversely associated with BMI across gender and age [100], this analysis suggests that BMI is also associated with total daily LPA.

Statistical analyses partially supported the second hypothesis, that *baseline BMI will no longer be inversely associated with light intensity physical activity participation at 3 months during a worksite intervention aimed at increasing light intensity physical activity participation to 30 minutes during the workday*. After adjusting for demographic variables, and accounting for clustering by worksite, models examining LPA changes from baseline to 3 months differed statistically across BMI category. Those in both the normal weight category and the overweight BMI category engaged in work-time LPA longer than those in the obese category. Further, individuals with BMI in the normal weight and overweight category had similar estimated increases in work time LPA. Although LPA was only measured at baseline and 3 months into a 12-month intervention, these current findings suggest that this worksite PA intervention may be similarly effective for those with normal and overweight BMI. Other work examining behavioral response in weight loss programs has suggested that individuals who are successful at adoption early on are more likely to have the most success over time [109, 110]. Therefore, these findings are encouraging for those in the overweight group but may be somewhat concerning for those in the obese group. While individuals in the obese group had the lowest work time LPA participation at baseline, this group did not increase LPA relative to those in the normal and overweight BMI categories. Further, this trend appeared to be more pronounced at 3-months. This work poses a challenge to future behavioral and environmental interventions to devise strategies to target and engage individuals with obesity so that they receive the full benefit of intervention. However, it will be very important to examine whether these differential effects persist over time as 12-month data become available. Additionally, it will be vital to assess whether those engaged in fewer minutes of LPA still receive the health benefits of the worksite intervention. Finally, future work using other environmental and worksite health interventions including those that target health screenings, diet and/or physical activity, weight management, and stress reduction should seek to examine potential differential effects by weight status.

Other findings in this study suggest a minimal association between age and both work time and total daily LPA, such that as age increases individuals participated in LPA longer. However, the effect size was very small. Using the results from baseline work time LPA (Table 13) a ten-year increase in age was associated with a 1.3-minute increase in work time LPA. This differs somewhat from work that has examined MVPA and age. Pate and colleagues found an inverse association between age and MVPA participation using a nationally representative samples [100]. These findings suggest that as age of the target audience increases, PA interventions that focus on LPA over MVPA may be more effective in behavior change and PA adoption. However, more work comparing the adoption and maintenance of different PA intensity goals is necessary.

Non-Hispanic white participants participated in significantly fewer minutes of LPA than those of other races. Previous research into workplace physical activity differences across race is limited. However, work examining leisure-time MVPA has found that non-Hispanic white adults were more physically active than adults with other racial backgrounds [111]. Our finding, that adults with other racial backgrounds are less sedentary during working hours, adds to the understanding of racial differences in work time PA for individuals with similar occupations. This difference in type, time, and location of physical activity should be explored further to improve intervention design. However, this sample was limited to primarily white adults, and more investigations that include diverse populations are necessary to gain a fuller understanding of PA intervention differences across race.

Another limitation includes the relatively short follow-up time of 3-months. This limits the conclusions that can be drawn about the effects of a full-scale worksite intervention on long-term continuation of LPA for adults with overweight and obesity. However, investigations of LPA participation at 12 and 24 months are planned once data become available. This work does not examine whether individuals met the 30 minutes of LPA recommended by interventionists. Future investigations should consider examining goal achievement as well as duration of activity.

Finally, although there was a large proportion of adults with overweight and obesity in this worksite sample, this was not a weight loss intervention and the PA recommendations were minimal. Therefore, this work is limited in its contribution to weight control and weight loss literature. However, insights remain regarding PA behaviors and adherence in adult working populations conveyed by this work.

Conclusion

This work highlights the importance of examining differential effects of interventions that target health behaviors. As behavioral intervention research continues, strategies to monitor and improve intervention efficacy for all participants in order to maximize health benefits will be pivotal. Moreover, as worksite environment interventions and policy changes that encourage PA uptake become more common, it is important to consider their effects on the large percentage of working adults with overweight and obesity.

Tables and Figures

Table 10: Sample descriptive characteristics for employees by BMI category

Characteristics	BMI <25	25 ≥ BMI <30	BMI ≥30
N,	173 (30%)	179 (31%)	223 (39%)
Demographics			
Age, mean (SD)	42.3 (12.0)	43.7 (11.1)	46.8 (10.6)
Gender			
Male, N (%)	45 (26%)	56 (31%)	53 (24%)
Female, N (%)	128 (74%)	123 (69%)	170 (76%)
Race			
Non- Hispanic White, N (%)	146 (84%)	131 (73%)	163 (73%)
Other, N (%)	27 (16%)	48 (27%)	60 (27%)
Educational Attainment			
Less than 4-year college degree, N (%)	36 (21%)	45 (25%)	87 (39%)
4-year college degree or more, N (%)	137 (79%)	134 (75%)	136 (61%)
Marital Status			
Married or Partnered, N (%)	112 (65%)	114 (64%)	123 (55%)
Not married or partnered, N (%)	61 (35%)	65 (36%)	100 (44%)
Sector			
Academic, N (%)	57 (33%)	66 (37%)	73 (33%)
Industry, N (%)	55 (32%)	58 (32%)	76 (34%)
Government, N (%)	61 (35%)	55 (31%)	74 (33%)

Table 11: Baseline work time light intensity physical activity association with BMI category

Model	Baseline PA	β(SE)	*p*
Unadjusted	***Fixed Effects:***		
	BMI Category		
	BMI <25	1.50 (1.37)	0.28
	25 ≥ BMI <30	1.11 (1.37)	0.42
	BMI ≥30	*ref*	*ref*
	Residual	*183.6*	
Adjusted	***Fixed Effects:***		
	BMI Category		
	BMI <25	3.05 (1.44)	0.04
	25 ≥ BMI <30	2.39 (1.41)	0.09
	BMI ≥30	*ref*	*ref*
	Age	0.15 (0.06)	0.01
	Gender		
	Female	1.86 (1.42)	0.19
	Male	*ref*	*ref*
	Race		
	Non- Hispanic white	-5.31 (1.46)	<0.01
	Other	*ref*	*ref*
	Marital Status		
	Married or Partnered	0.10 (1.22)	0.94
	Not Married	*ref*	*ref*
	Education level		
	Less than 4 year college degree	0.71 (1.43)	0.62
	4 year college degree or more	*ref*	*ref*
	Residual	*176.3*	

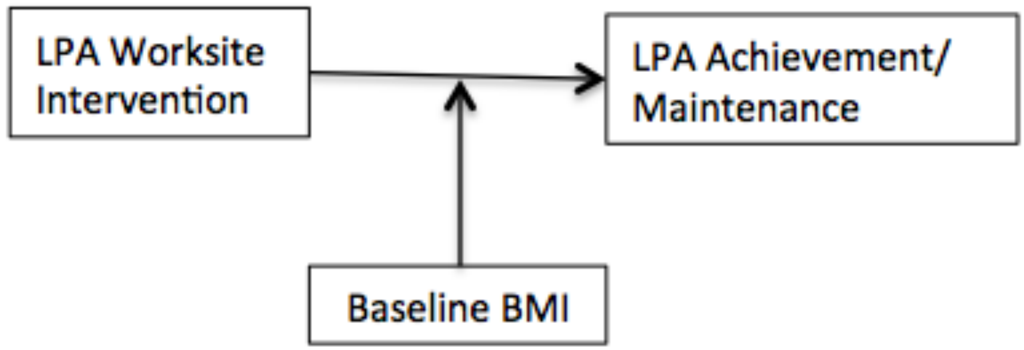
Table 12: Baseline total daily light intensity physical activity association with BMI category

Model	Baseline PA	β(SE)	*p*
Unadjusted	***Fixed Effects:***		
	BMI Category		
	BMI <25	12.04 (2.64)	<0.01
	25 ≥ BMI <30	6.15 (2.65)	0.02
	BMI ≥30	*ref*	*ref*
	Residual	*702.8*	
Adjusted	***Fixed Effects:***		
	BMI Category		
	BMI <25	13.63 (2.80)	<0.01
	25 ≥ BMI <30	7.77 (2.74)	<0.01
	BMI ≥30	*ref*	*ref*
	Age	0.25 (0.11)	0.03
	Gender		
	Female	-3.39 (2.75)	0.22
	Male	*ref*	*ref*
	Race		
	Non- Hispanic white	-3.61 (2.83)	0.20
	Other	*ref*	*ref*
	Marital Status		
	Married or Partnered	2.92 (2.37)	0.22
	Not Married	*ref*	*ref*
	Education level		
	Less than 4 year college degree	-4.42 (2.72)	0.10
	4 year college degree or more	*ref*	*ref*
	Residual	*681.9*	

Table 13: Three-month work time light intensity physical activity association with BMI category

Model	3-month LPA	β(SE)	*p*
Unadjusted	***Fixed Effects:***		
	BMI Category		
	BMI <25	2.13 (1.25)	0.07
	25 ≥ BMI <30	1.72 (1.20)	0.15
	BMI ≥30	*ref*	*ref*
	Residual	*73.7*	
Adjusted	***Fixed Effects:***		
	BMI Category		
	BMI <25	3.38 (1.28)	0.01
	25 ≥ BMI <30	2.82 (1.25)	0.02
	BMI ≥30	*ref*	*ref*
	Age	0.13 (0.05)	0.01
	Gender		
	Female	-1.73 (1.26)	0.17
	Male	*ref*	*ref*
	Race		
	Non- Hispanic white	-4.18 (1.30)	<0.01
	Other	*ref*	*ref*
	Marital Status		
	Married or Partnered	-0.23 (1.04)	0.82
	Not Married	*ref*	*ref*
	Education level		
	Less than 4 year college degree	0.08 (1.26)	0.95
	4 year college degree or more	*ref*	*ref*
	Residual	*74.2*	

Figure 11: Proposed effect of LPA worksite intervention modified by BMI



CHAPTER 6

DISCUSSION AND IMPLICATIONS FOR FUTURE RESEARCH

Summary of Findings:

This dissertation offers insight into a variety of topics at the intersection of weight, physical activity, and behavioral interventions. These included testing a novel analysis method for behavioral research, examining potential indicators of behavioral disengagement, and exploring differences in behavior change in response to intervention by baseline characteristics. The first manuscript used a decomposition method to examine mediating and moderating effects of MVPA prticipation on the association of life events and weight loss mainteance. The use of this analysis method is a unique and innovative way to explore the effects of behavioral changes within the context of one's personal and social environment. Results showed that while the total effect of life events was significantly associated with weight maintenance, there was no statistical evidence for mediating or moderating effects of MVPA achievement. The statistically significant direct effect of the occurrence of life events controlling for MVPA participation and the small non-significant estimate of percentage mediated suggested ruling out the mediation effect. That is, the occurrence of life events did not affect weight through the pathway of low MVPA participation. Further, there was not enough statistical evidence to make a definitive conclusion concerning the interaction of MVPA participation and occurrence of life events on weight loss maintenance. This first manuscript offered clarification about the relationship of external social circumstances on physical activity behavior and weight loss maintenance. The second and third manuscripts explored two different types of intervention elements that may aid in the development and improvement of programs that aim to increase physical activity levels in adults with overweight and obesity.

This second manuscript explored self-monitoring indicators to identify individuals at risk for weight regain and MVPA disengagement. This work was novel in examining the impact of specific self-monitoring characteristics during a behavioral weight loss intervention on MVPA and weight out to 24 months. Late onset of PA self-monitoring increases in the number of gaps in physical activity tracking, and increases in the length of each gap were associated with lower MVPA participation at both 12 months and 24 months. Further, consistent PA self-monitoring was associated with higher MVPA reporting at 12 and 24 months. Several PA and dietary self-monitoring characteristics were associated with weight at 12 and 24 months as well. Late onset of PA self-monitoring, but not dietary self-monitoring, was associated with higher weight at 12 and 24 months. Increases in the total number of gaps in diet and physical activity tracking were both associated with increases in weight. Consistent diet and physical activity tracking was associated with lower weight at 12 and 24 months. Finally, increases in MVPA self-monitoring gaps lasting longer than 12 weeks were associated with both lower MVPA participation and higher weight. The use of 24-month follow-up time offered the potential to evaluate how early signs of behavioral lapse and relapse were associated with long-term behavioral and weight maintenance outcomes. While defined gap lengths in self-monitoring did not uniformly predict weight or MVPA outcomes, findings suggest that gaps in tracking as early as the second week of intervention may indicate behavioral disengagement. This analysis offered a clearer understanding of the effects of self-monitoring gaps and potential use of these gaps to improve intervention design and implementation. However, this manuscript was limited in its recommendations for strategies to help participants achieve more physical activity and reach the recommended 250 minutes of weekly physical activity recommended for weight loss and maintenance. Overall, few participants (25%) were able to achieve this recommendation, even in this presumably motivated weight loss seeking sample. In order to examine more achievable population-wide recommendations for health, the third manuscript examined outcomes of a worksite intervention to increase LPA.

The final manuscript examined differences in LPA participation by BMI category. The study sample, similar to the sample in the weight loss intervention, had a large proportion of women and a large proportion of college-educated individuals making findings across the two study samples used in this dissertation somewhat comparable. Further, by assessing LPA via an intervention not designed to result in weight loss, the results from this sample began to uncover differences between weight loss and non-weight loss seeking samples in regards to PA behaviors and interventions. Major findings from this analysis suggested that at baseline there were slight statistical differences in work time LPA across BMI categories. Further, there was an inverse relationship between BMI category and total daily LPA so that those in the normal weight and overweight BMI categories participated in more LPA than those in the obese category at work and throughout the day. At three months, those in the normal weight and overweight BMI categories participated in work time LPA longer than those in with obese BMI. This suggests that this worksite PA intervention may be similarly effective for those with normal and overweight BMI. However, it will be important to examine the full effects at 12- and 24-month follow-up in this trial to understand more fully how obesity status may affect initial adherence and maintenance of LPA recommendations.

Table 14: Overview of major findings

Aim1. Identify changes in weight following a lifestyle weight loss program by examination of the impact of physical activity in the context of life events on those changes.
• The total effect of reporting life events on weight regain within a lifestyle weight loss intervention was influenced by MVPA participation during the maintenance phase of the trial. • Results of the decomposition of mediating and moderating effects suggest the effect of greater reported life events on weight regain within an active weight loss intervention was not mediated by physical activity during the maintenance period. • Statistical evidence to support the effect modification of the reporting of life events on weight maintenance by MVPA was insufficient.
Aim 2. Examine the effect of physical activity tracking behavior during active weight loss intervention on moderate to vigorous physical activity achievement and maintenance, weight loss at 12 months (immediately following intervention), and weight loss maintained at 24-month follow-up.
• Later onset of physical activity self-monitoring during intervention and greater frequency of gaps in physical activity self-monitoring were associated with lower reported physical activity levels measured at 12-month and 24-month follow-up. • Increases in gaps lasting greater than12 weeks were associated with lower reported physical activity levels measured at 12-month and 24-month follow-up. • Later onset of physical activity self-monitoring during intervention was associated with higher weight at 12-month and 24-month follow-up. • Total number of gaps in physical activity self-monitoring and dietary self-monitoring during intervention were associated with higher weight at both 12 months and 24months. • Increases in both physical activity and dietary self-monitoring gaps lasting greater than12 weeks were associated with higher weight at 12-month and 24-month follow-up.
Aim 3. Examine the association between baseline BMI and light intensity physical activity at 3 months during a light intensity physical activity worksite intervention.
• BMI category was associated with total daily light physical activity measured at baseline, so that employees with BMI in the obese category participated in LPA less frequently than employees with lower BMI at the time of study enrollment. • BMI category was inversely associated with LPA participation at 3 months into a worksite intervention aimed at increasing light intensity physical activity participation, so that employees with BMI in the obese category participated in work time LPA less frequently than employees with overweight or normal BMI.

Future Directions:

Findings from this dissertation highlight several directions for both physical activity and weight loss maintenance intervention research. Following data collection at the 12-month and 24-month time points of the Stand & Move at Work trial, it will be important to examine LPA participation by BMI to assess whether these early trends in LPA achievement remain. Additionally, comparing differences in PA achievement and adherence between the two physical activity level recommendations (LPA vs. MVPA) either across these two study populations or in new intervention trials should also be considered. Although two of these papers address MVPA and maintenance in a sample of individuals actively trying to lose weight, and the final paper examines a LPA intervention in a worksite population, more work is needed to improve understanding of which type of recommendation is more easily achieved and maintained by adults, whether interested in weight loss or not. Future comparisons of the Stand & Move at Work LPA participation at 12 and 24 months and the Tracking study's MVPA participation at 12 and 24 months may help to address these questions.

Further examination of the relationship between other demographic characteristics and LPA and MVPA is important. While the weight loss sample showed that age was inversely associated with MVPA participation, the worksite sample found that age was positively associated with LPA participation. Similar relationships were found with race and gender as well. This information could be used to inform and test tailored health messaging and targeted intervention research in the future. Interventions that utilize a stepped approach to physical activity should also be considered and tested for individuals.

As technological advancements allow for improved physical activity measurement and intervention support, identifying factors necessary to expand mobile interventions and ensure success continues to be pivotal. This could include common factors that protect against the deleterious effects of significant life events and simultaneously encourage physical activity, such as social support. One limitation highlighted in paper 2 is that although MVPA has been shown to improve weight loss maintenance [31], this analysis does not examine this relationship directly. In the future, mediation models that explore the impact of PA and dietary self-monitoring on weight loss and maintenance independently of MVPA as well as through MVPA should be considered. Following this current analysis, meditational models should additionally be considered to examine the mechanism between PA tracking, PA achievement, and weight directly.

Finally and perhaps most importantly, assessing the themes in all three manuscripts in more diverse populations is imperative for public health efforts. Both the weight loss sample and the worksite intervention sample were primarily white, college-educated and married adults. Due to the disproportionate rates of obesity in minorities as well as low-income populations, more work is needed to explore PA uptake and adherence as well as weight loss and successful maintenance. For example, Foley and others have illustrated ways that mobile phone applications may be utilized in low-income populations to improve behavioral and health outcomes including weight, CVD and diabetes indicators[112]. Using models such as this, more behavioral weight loss intervention research should examine whether mobile devices or other technologies, could effectively reach more diverse populations to encourage long-term PA participation. Work that explores intervention characteristics that can be paired with these devices to monitor engagement and more effectively produce desired behavior change and health outcomes will continue to be an important topic in health behavior research. Finally, as medicine becomes more personalized and mobile devices become more ubiquitous, behavior change research will likely continue in these directions, highlighting the timeliness of the intersection of the topics covered in each of these manuscripts.

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